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BRITAIN'S FUEL PROBLEMS.

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THE Editors do not hold themselves responsible for the opinions expressed in the various chapters of this work.

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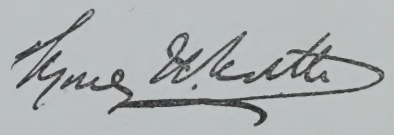
GENERAL EDITOR'S NOTE.

In conceiving the idea of this work some months ago and reviewing its comprehensive character and scope, I realised that its achievement was not a task which could be fulfilled single-handed, and that it could be brought to a successful conclusion only by the enthusiastic co-operation of a group of Editors and Contributors, each a specialist in his own particular branch of work. Without this co-operation, for which I desire to express my grateful thanks and appreciation, the present volume could not have been completed.

The subject is so many-sided, the problems associated with its varied aspects so urgent, that the presentation in one volume of existing knowledge and practice should be of undoubted service to all scientists and industrialists throughout the world.

Though the treatment of the subjects is necessarily concise, in submitting the work to those interested in fuel treatment and utilisation it is believed that this will in no way detract from its value as a practical exposition of the various fuel problems of the day.



December, 1927.

FOREWORD.

By The Right Honourable Sir Alfred Mond, Bart., P.C., LL.D., M.P.

The publication of this work, dealing comprehensively with almost every aspect of the fuel problems of the present time, is a powerful sign of the national awakening to the urgency of those problems which have taken place since the war.

The imperative need for new and sustained researches into every phase of the winning and of the most economical utilisation of coal cannot be too often stressed. The coal industry plays such a vital part in the industrial activities of the nation, and is so closely interlinked with our general prosperity, and our great coalfields are so obviously one of our richest assets, that the wonder is that its many problems have not been tackled on organised and scientific lines long before this.

Apart from reorganisation in the production of coal, the problems of fuel economy may be pursued from three different directions. First, there is the economy to be obtained from existing plants now in actual operation; second, the economy resulting from the development of the use of electricity; thirdly, there is the future development of fuels, such as the new uses and treatment of coal, oil and the elements.

These are the three directions in which the fuel technicians of to-day can most usefully conduct their enquiries, and assist the various industries and interests of this country, and the community at large. Fuel problems may again be divided into two sections, the domestic and the industrial. In either section they are extremely diverse, but not incapable of immediate amelioration and ultimate solution, as a perusal of the articles in this volume will prove.

The vast range of fuel technology in domestic uses is too frequently underestimated, sometimes, indeed, altogether ignored. The question of the heating of buildings, the proper appliances to use for this purpose, the smoke nuisance, and so on, are among the problems which intimately affect each and every member of the community.

On the industrial side the problems are naturally still more diverse and more important. The conditions under which the coal is won, pit equipment and pit-head appliances, and the bringing of our practice up to the scientific level of some of our competitors, is one line of attack. The best British methods underground cannot be improved upon, but there is vast room for improvement in the surface equipment of the majority of our pits. The removal of dirt and extraneous matter from coal at the pit-head is another problem which is receiving increasing attention. Several new processes are in sight, and the many thousands of tons of useless dirt which are at present hauled about the country will doubtless be greatly lessened in the near future. We are waking up to the value and economy of clean coal.

The grading of coal at the pit-head for various markets and uses, together with the establishment of power stations and plant for the use of inferior coal, will save a large percentage of valuable fuel which is at present being wasted. Then, again, we have the question of transport, the need for co-ordination, for larger wagons, and more modern discharging facilities, matters in which our Continental rivals are, too, far ahead of us.

Coming to the question of fuel economies in existing plants, we run up against very extensive problems. It is obvious that many millions of capital are invested in old plants, and the process of transition to the new plant and new equipment must inevitably be a slow one.

Nevertheless, these problems must be faced. Not all boiler plants which are working to-day are working at anything like—not the maximum, but even good practice. A very large percentage are still worked in an entirely unscientific manner. Allied with this is the question of purchasing coal on its calorific value. I may say that, for many years in one of the concerns with which I am associated, no coal has been bought until it has been tested carefully by the scientific staff for its heating value.

Fuel technology concerns every factory, and generally every process in the factory. I mention this because I sometimes see it regarded as if the whole function of the fuel technologist was to deal with the question of raising power cheaply. Take the steel industry. The amount of fuel used for power is a bagatelle compared with the amount used in the furnace processes. That the iron and steel industries are becoming fully alive to the importance of fuel economy will be manifest from the articles in this volume. In Germany they have established organisations since the war which, by proper control and measuring methods, have saved fifteen per cent. on fuel alone in iron and steel production. A similar saving can only be a matter of a short time in this country.

As regards existing boiler plant, great economies may be effected by the better purification of boiler water, the more efficient use of superheaters, of mechanical stokers, chain grates, ash-conveyors, and other auxiliaries. There are also the problems of direct firing, and the use of high-pressure and exhaust steam. The application of various systems of pulverised fuel is becoming more and more widely adopted, especially in new plants, and its advantages are increasingly recognised in this country.

Coming to the future of electricity, we are already, with the establishment of the Central Electricity Board, tackling the problem on a broad national basis. We have yet to see in this country the creation of generating stations which in the United States would be considered any size at all. In fact, the future of electric supply is full of enormous potentialities for all industries, not excluding agriculture.

It must not be forgotten that the amount of energy at present recoverable as power from fuel is relatively still only a very small amount—something like a quarter of the amount theoretically possible. The recovery on a larger scale is an urgent problem, which awaits solution. Then we have the co-ordination of gas and electricity undertakings, and the striking of the right economic balance, related to which is the question of the erection of fuel and power factories at the pit-head.

Coming to the third of our series of problems, that of the future utilisation of fuel and its by-products, we have the epoch-making fact that the problem of increasing the hydrogen content of coal, thereby converting it into oil, is already solved, and its application and full exploitation in this country cannot be long delayed. When fully applied, it will constitute something like a fiscal and industrial revolution in this country.

In by-product recovery we have sometimes been accused of national lethargy, but here, again, progress has been made, and we may look forward, in a few years, to substantial returns in this direction. As this volume will show, the whole question of coal distillation is simply bristling with problems, in spite of the number which have already been successfully and brilliantly solved.

The above are but a few of the points to be discussed. What I wish to emphasise most is the need for a national conscience with regard to the economic use of fuel. Great Britain possesses about $2\frac{1}{2}$ per cent. of the world's estimated reserves of coal, and she is drawing on her resources at a relatively greater rate than many of her competitors. This is a great national problem.

As I have remarked, there has been a great awakening to the urgency of this problem, and the establishment of such a body, for instance, as the Institute of Fuel is another sign of that awakening. The chemical industry, again, has a very great influence on these fuel problems, and with additional facilities for co-operation, will, undoubtedly, be a source of further economies and increased uses.

All over the country there are industries, great and small, which, from a fuel point of view, could be run much more efficiently with but little more effort and attention. The habit of saving coal for its own sake would, in the aggregate, have a tremendous effect on national economies.

I have given but a few of the reasons why I plead for fuller use of fuel technology and the trained fuel technologist in all our industries. We are at the dawn of a new era in the utilisation of fuel, and this volume serves in striking and authoritative fashion to indicate the lines on which future advances should be made. Fuel economy is a practical form of patriotism. It spells efficiency in production and prosperity in national economics.

INTRODUCTORY ARTICLES.

FUEL ECONOMY IN AMERICA.

By Prof. R. T. Haslam.

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Before entering upon a detailed consideration of the trend of fuel economy in the United States, it is essential to make at least a general survey of the fuel resources of America and of the uses to which the fuel is now put. The United States is fortunate in having a plentiful supply of high-grade coal, oil, and natural gas. Indeed, the supplies of these fuels have been so great and the prices so low that until quite recently there was very little incentive for industry to economise and conserve these most valuable natural resources. Only within the past ten or twelve years have prices become sufficiently high to arouse a deep and genuine interest in fuel economy. However, industry is now fully alive to the problem, and the widespread interest is indicated by the great success of the first International Coal Conference held in the fall of 1926 at Pittsburgh, Pennsylvania, and by the interest shown in the technical papers to be presented at the first national fuel meeting held in St. Louis in October, 1927, under the auspices of the American Society of Mechanical Engineers. Numerous colleges and technical schools are now offering courses in fuel technology, and the attendance is constantly increasing.

The abundance of fuel in America is displayed graphically in Figure 1. Of all the coal in the known deposits of the world, more than 60% is in North and South America, as this figure shows; and, furthermore, three-fourths of this amount lies within the United States, thus making this country, in this respect, one of the most fortunate in the world. Over one-half of these known deposits in the United States are bituminous, the rest being lignitic. In addition, the country has large supplies of oil and natural gas, providing, as it does, three-fourths of all the present world's production of petroleum.

Figure 2 shows the uses to which coal is put in the United States. As will be noted, most of it is employed in the industrial steam trade, although the railroads are a close second. It may be a surprise to many to note that the use of coal in the home for domestic heating occupies third place. The coal consumption of the Public Utilities tends to increase at the expense of that of individual industries, about which more will be said later.

Most of the coal consumed in the United States comes from mines having thick coal seams, lying at a depth of two or three hundred feet. This is, of course, different from the situation in England, where the seams are not so thick and where the average depth is probably at least four times as great. An increasingly large percentage of the coal is being taken from non-union mines and mining machinery is widely used, approximately 65% of the coal being obtained by machinery in the United States, as compared with less than 20% in England.

Although there is a great tendency towards the rapid development of hydro-electric power, and towards the combination of hydro-electric stations with steam stand-by or auxiliary plants, the actual energy produced by water power in the United States is only a little over five per cent. of the total energy produced.

For an intelligent consideration of the problems in fuel economy it is also necessary to keep in mind some of the general characteristics of the United States and its people. For example, the high price of labour creates a constant and powerful demand for the replacement of labour by power-driven machines. This is producing a very rapid growth in the per capita use of power, as shown by Fig. 3. Furthermore, the characteristics of the American people are such that machinery and equipment are changed rapidly whenever better and more efficient designs appear, and, consequently, there is probably a less deviation in this country than elsewhere between the most efficient plant and the average. This tendency to adopt readily new developments is illustrated by Fig. 4, which shows the rapidity with which pulverised coal is being used in boiler plants in this country. American industries, also, display a strong tendency to coalesce into large manufacturing units, a tendency which the Government has sometimes opposed in the past, although its attitude now seems to be changing.

To illustrate the fuel situation in the United States and the steps being taken to secure increased fuel economy a few industries will be discussed generally and briefly.

Railroads.

Considerable progress in fuel economy is being made by the railroads and the fuel required for both passenger and freight service is constantly decreasing. Special types of locomotives for special service are constantly being designed and the size of locomotives for regular freight and passenger service is as constantly being increased.

During 1926 the fuel required to haul 1,000 tons of freight and equipment one mile was 137 pounds, as compared with 140 pounds in 1925, which was the best previous record. Similar improvements were made in the hauling of passenger trains, where the fuel requirements were 15.8 pounds of fuel per car mile in 1926, as against 16.1 pounds in 1925, and 18.8 pounds in 1920. This improved efficiency may be attributed in great part to the use of superheaters, better selection of coal, constant education of the firemen, and higher steam pressures. In this country, superheaters were little used prior to 1910. For example, in 1912 only about 2,000 locomotives were so equipped. Now the practice is quite common. The ordinary working pressure for steam locomotives, at the present time, probably, does not exceed 250 pounds, but in the past year several experimental locomotives have been built utilising pressures up to 400 and 450 pounds.

The trend in locomotive design is indicated by the table below, which gives a comparison of the passenger locomotives used by a representative railroad system (the Baltimore and Ohio) from 1893 to the present time.

TABLE I.

Year.	Tractive force in pounds.	Grate area in sq. ft.	Evaporative surface in sq. ft.	Superheating surface in sq. ft.	Steam pressure in lbs./sq. in.
1893	17,300	24.7	1,693	—	165 lbs.
1896	23,750	34.3	2,160	—	190 „
1910	27,400	65.5	2,350	—	250 „
1913	34,200	56.5	2,567	587	190 „
1919	40,800	56.7	3,341	794	200 „
1927	50,000	70.3	3,876	932	230 „

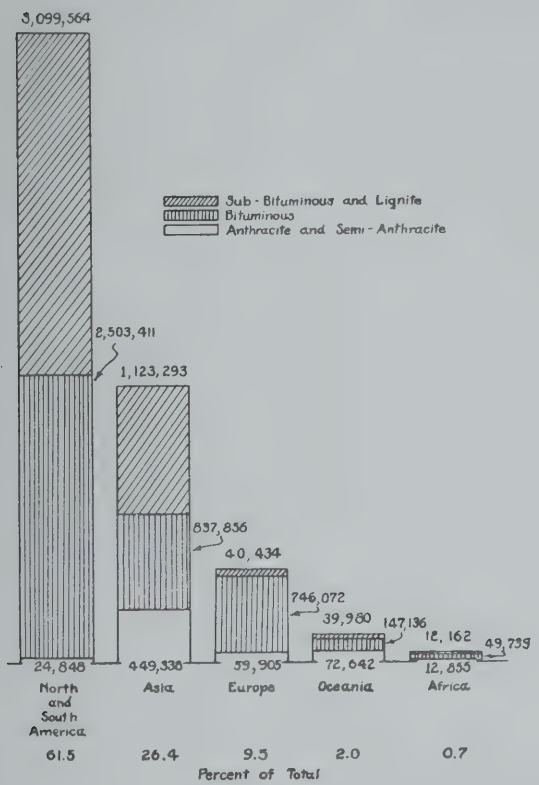
This table shows the steady increase in the size of locomotives as indicated by the tractive force, the grate area and the heating surface. The increase in steam pressure and superheating area are, also, shown clearly. Inasmuch as, the railroads of the United States use about one quarter of all the coal mined, and since the overall efficiency of a steam locomotive at the present time is probably around 8%, the importance and possibilities of improvements in this field are obvious.

Public Utilities.

Probably, the greatest strides in fuel economy in America have been taken by the Public Utilities supplying electric current to the homes, factories, and street railways. In view of this fact, and since all industrial power plants have generally followed and adopted the developments in the public utility field, this industry will be discussed in more detail than any other.

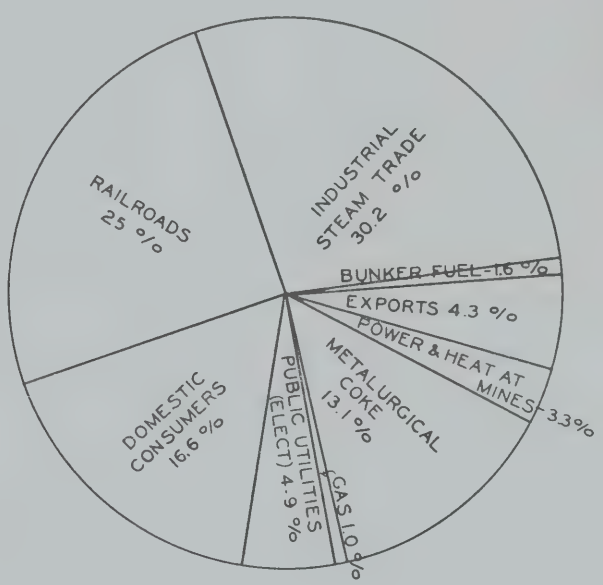
Progress has been made, not only through the better design and operation of equipment, but also by the shutting down of small, obsolete plants and by the interlocking of various large plants into one common system, thereby improving the general load factor. For example, in the State of Wisconsin very nearly all privately-owned power plants have been shut down except those where exhaust steam is used for process work, and the power formerly generated at these plants is now being supplied by the large Public Utilities. In the State of Wisconsin, as a whole, the *average* performance for 1926 was 2.2 pounds of coal per kilowatt-hour, while at the Lakeside station, the largest and most progressive central station in this State, the coal consumption was only 1.2 lbs. per kilowatt-hour. The United States Geological Survey shows that, in 1926 there was a 12% increase over the previous year in the electrical load generated by Public Utilities power plants. About one-half of this growth is due to the change of power generation from private industrial power plants to the large central stations of the Public Utilities, and to the absorption of these smaller stations.

The interlocking of steam and hydro-electric stations, and the tying together of one company operating in one district with another company operating in another district, is proceeding at a rapid rate, particularly in the north-eastern part of the United States. For example, the long distance electrical transmission lines of the north-eastern section of the country were recently tied together between Boston, Massachusetts and Chicago, Illinois, a distance of approximately nine hundred miles. The improvements resulting from increased load factor, the shutting down of small stations, and the increased dependability and flexibility of such systems have been very marked. Large steam stations, operating along the Atlantic Coast with the plentiful supply of condensing water, and with coal delivered by boat, have been connected with hydro-electric power plants, located on our northern rivers, thus eliminating the necessities for small, inefficient power plants at intermediate points.



COAL RESOURCES OF THE WORLD
BY CONTINENTS.
FIGURES ARE IN MILLIONS OF NET TONS

FIG. 1.



THE UTILIZATION OF COAL
IN THE UNITED STATES

FIG. 2.

The increase in size of our Public Utilities has been accompanied by a remarkable improvement in fuel economy. Thus, Table II., given below, illustrates not only plant practice for stations of different size, but, also, the marked effect that size has on operating efficiency.

TABLE II.

Size of station.	B.T.U.'s consumed per kw.-hour generated.
1,000 to 10,000 kw.	55,800
16,000 to 40,000 kw.	30,200
40,000 to 200,000 kw.	24,500
More than 200.000 kw.	19,800

TABLE III.

Year.	Pounds of coal per kw.-hour
1900	6.9
1905	5.3
1910	2.98
1915	2.70
1920	2.47
1925	2.06

Each item in Table II. is based on the average of a relatively large number of stations.

Moreover, in 1919 the central electric stations generated about 25,000,000,000 kilowatt-hours with a coal consumption of 3.2 pounds of coal per kilowatt-hour, whereas in 1926 they generated practically 50,000,000,000 kilowatt-hours with a coal consumption of 1.9 pounds per kilowatt-hour.

This general trend is illustrated, more in detail, by Table III., which shows the consumption of coal per kilowatt-hour for the entire Commonwealth Edison system of Chicago, Illinois, over the past twenty-five years.

It is also interesting to note the fuel economy obtained in the following stations of the Commonwealth Edison Company, built during this same period.

TABLE IV.

Station.	Year erected.	Pounds of coal per kw.-hour generated.
Harrison Street	1900	5.9
Fisk Street	1907	3.17
Calumet	1923	1.63
Crawford Avenue	1924	1.52

The fuel economy of this large public service system, is particularly remarkable when it is considered that low-grade central Illinois coal containing 15% of moisture, 15% ash and 4% sulphur is being used. The ash has a very low fusion point and the coal is a high oxygen coal. It has been estimated that, by using this fuel, 15,000 to 15,500 B.T.U.'s per kw.-hour is comparable with 14,000 to 14,500 B.T.U.'s per kw.-hour with high-grade eastern U.S. bituminous coal. In other words, with this coal 1,000 B.T.U.'s extra per kw.-hour is required as compared with a good high-grade bituminous coal.

The United States Geological Survey reports that the annual output of electricity from Public Utility plants in the United States is increasing at the rate of a little less than 12% per year, and that the fuel consumption in the past year was one-tenth of a pound of coal per kw.-hour better than the previous year. This improvement means a saving of over 2,000,000 tons of coal per year. The extensive growth of our Public Utilities power plants, and their remarkable improvement in fuel economy, have been material factors in keeping the total coal consumption approximately constant during the past few years, although the use of power per capita has risen enormously. The importance to this country of greater and larger stations operating with very high coal efficiencies, is shown by the fact that the entire electrical output of England amounts to something over 6,000,000,000 kw.-hours, with a coal consumption not far from $4\frac{1}{2}$ pounds per kilowatt-hour, whereas in the Metropolitan district around New York City, there were generated by the New York Edison Company, something over 7,000,000,000 kilowatt-hours with a consumption of approximately two pounds of coal per kilowatt-hour. The full importance of this performance cannot be measured by the amount of fuel saved by this particular company, or by the larger Public Utilities central stations themselves. In obtaining these high efficiencies, these companies have carried out a very large amount of experimental investigation and development, and the results have been made public. Such performances have been a constant stimulus and incentive to higher fuel efficiency in other industries.

Pulverised fuel firing.

In discussing the steps taken to improve the efficiency with which electricity is generated from coal, first place should be given to the use and development of commercially satisfactory pulverised fuel systems, because, not only has this form of combustion attained efficiencies somewhat greater than those obtainable with other methods of burning coal, but, it has furnished the stimulus for many of the latest improvements in other lines. For example, as a result of the competition with pulverised coal the mechanical stoker has now been developed to a degree unthought of a few years ago. In the United States, there are to-day, pulverised coal-fired boilers which are operating month in and month out at a gross efficiency very close to 90%. These boilers, of course, are fitted with economisers or air preheaters, and are operated with flue gas temperatures of less than 250° F.

The Lakeside station of the Milwaukee Electric Railway & Light Company, using pulverised coal, reports a 5 to 8% increased economy with this method of firing than with the older stoker method.

Pulverised fuel, also, permits the use of a wider variety of fuels in a given installation, and also the burning of lower-grade fuel with high ash and moisture content, an important factor in the conservation programme of the nation.

There has been a marked reduction in the necessary furnace size for pulverised coal firing, a reduction which has been made possible by the use of water-cooled furnace walls, and increased turbulence *within* the furnace. Prior to 1926, practically all the efficiently operated powdered coal installations were limited to from 10,000 to 15,000 B.T.U.'s liberated, per cubic foot of furnace volume per hour for the most economical operating results. To-day, there are, in successful operation, several installations, employing a high degree of turbulence, in which the heat is released at a much higher rate, namely, from 40,000 to 60,000 B.T.U.'s per cubic foot per hour. Not only has this lowered the space required for combustion, but the entire boiler room building may be made smaller for a given output. This, of course, decreases the fixed charges and contributes, materially, to the production of cheaper electricity.

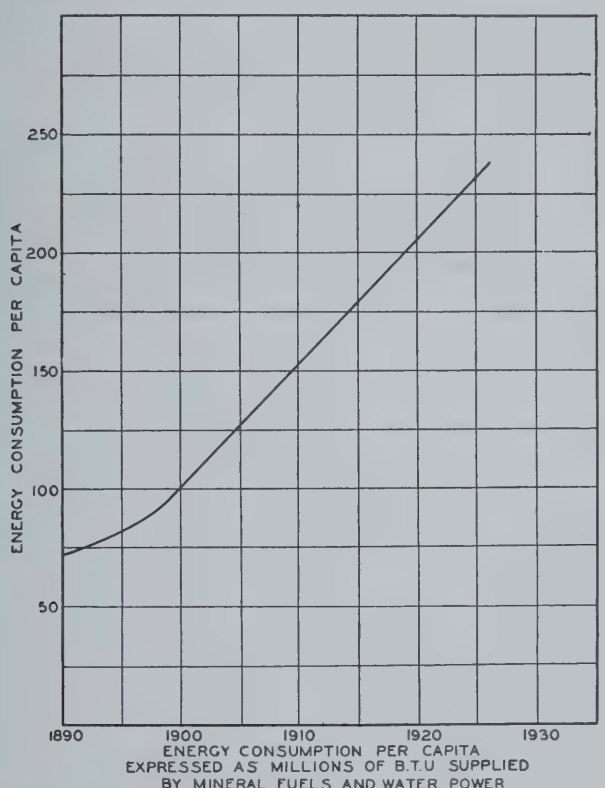


Fig. 3.

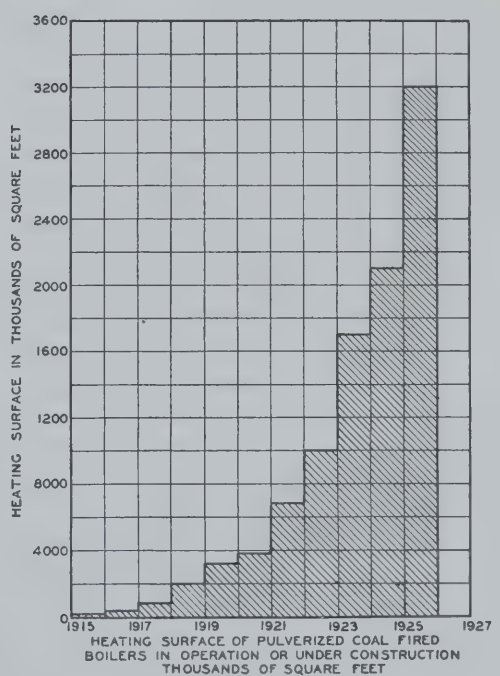


Fig. 4.

Such development makes possible the successful use of pulverised coal firing in fire-tube boilers, both of the horizontal return tubular, and of the Scotch marine type. Inasmuch as there are many of these types of boilers in industrial plants in the United States, the importance of suitable developments along these lines is obvious. The present operating efficiencies on a vast number of these small installations using old methods of firing, will average between 40% and 50%, whereas, a number of the same type of installations using pulverised coal are operating with efficiencies ranging from 75% to 80%. Thus, the savings possible reach, in the aggregate, to a not inconsiderable amount.

As already mentioned, the use of water-cooled furnace walls has been one of the principle contributing factors making possible the practical solution of the problem of increased furnace capacity. The release of from 40,000 to 60,000 B.T.U.'s per cubic foot per hour, in powdered coal-fired furnaces would not be possible

with refractory walls. It is only by the use of water cooling that such results may be looked for. Although both bare water-cooled walls, and refractory lined water-cooled walls have been widely utilised, the latter appears to be gaining favour, first, by reason of the reduction of unburned combustible thereby obtainable, and second, by reason of the flexibility in operation which seems impossible with black walls (*i.e.*, bare water-cooled walls). With the latter, at low ratings, the unburned combustible losses mount rapidly, and frequently, it is difficult, if not impossible, to sustain flame propagation. In addition to water-cooled walls, water screens in the bottom of the furnace are widely used, and to-day, water-cooled arches are coming into use more and more. Water-cooled construction of furnace walls has two additional advantages; first, it permits the use of air in amounts closely approximating the theoretical requirements of the fuel (*i.e.*, a low percentage of excess air is used with resulting higher flame temperature), and second, by eliminating adherence of clinker to the walls of the furnace, the furnace maintenance is materially decreased. As a result of this water cooling, it is possible to run boiler furnaces at ratings to around 400% of normal load.

Unit pulverisers.

In pulverised coal firing, there has been a considerable development in the use of unit coal pulverisers. Some of these pulverisers have been developed with an effective operating range as high as ten to one in a single unit, thus making possible a wider range of rating than the four to one ratio, heretofore considered the maximum obtainable with this type of equipment. At the same time, considerable improvement has been made in cutting down power consumption, lowering maintenance expense and producing coal ground finer and more uniformly. These unit coal pulverisers have proven successful commercially, in handling coal containing moisture as high as 35% (Dakota lignite), without the use of a dryer. Power consumption has approached that obtainable with large central grinding systems.

In the last year or two, there has also been a large increase in the use of air preheaters in power plants, and improvements, as a result of this development, are many. In the first place, it permits the use of regenerative heating of the boiler feed-water by bleeding steam from the various stages of the turbine into the feed-water (instead of heating the feed-water in economisers), which procedure increases the efficiency with which this heat is converted into power. In addition, the use of preheated air usually materially cuts down the loss due to unburned fuel. For example, in one large well-operated station the use of preheated air with under-feed stokers increased the efficiency from about 76% to nearly 83%. One-third of this increase was due to the smaller ash-pit loss, while the other two-thirds was due to the lower stack losses, resulting from the use of the preheaters. In using preheated air with chain grate stokers, consideration must be given to the expansion which occurs, and stokers have been designed to take care of this. The maximum temperature of preheated air is, usually, around 400° F. In operating a chain grate under these conditions there is a tendency, with some coals, for the tar in the coal to melt and run, consequently, increasing the resistance to the passage of air through the fuel bed. With such coal the temperature of the preheated air must, usually, be below the maximum just given.

There is a constant tendency toward the use of higher steam pressures in all of the modern power plants. The maximum pressure, at present, is 1,200 to 1,300 pounds per square inch, with 1,400 pounds contemplated. This pressure is being used at two stations in the United States, namely, the Edgar station outside Boston, Mass., and the Lakeside station of the Milwaukee Electric Railway and Light Company of Milwaukee, Wisconsin. At the latter station, a 1,250-pound boiler has been superimposed upon the older, original 300-pound station (two boiler room sections). The steam generated at 1,250 pounds pressure expands through a 7,000-kilowatt turbine, returns to the furnace for reheating, and is then discharged into the regular 300-pound steam main for further expansion through the regular turbines. In stage reheating, the steam is usually taken out of the turbine at a pressure equal to about three-tenths of the original pressure. Much of the need for reheating and returning the steam to the turbine is to cut down condensation in the lower pressure stages of the turbine. Stage reheating is used when the pressure of the steam exceeds 350 to 400 pounds, per square inch. The 1,250-pound boiler is fired with the pulverised coal system, the burners being automatically, and gradually, turned off as the steam pressure reaches 1,300 pounds, per square inch. At this pressure, all of the burners are automatically shut down. As the steam pressure drops down to 1,250 or 1,200 pounds, per square inch, the powdered coal burners are, automatically, turned on in order to maintain pressure at these figures. The effect of the 1,250 pressure installation at this station has been to improve the economy of the entire plant by about 6 per cent. Extensions

to the high-pressure system are contemplated, which should result in a 12 per cent. saving. Actually, this results in a coal saving of 16 per cent. over an installation of equal capacity operating at 300 pounds, per square inch, pressure only.

In addition to the two high-pressure stations mentioned, there are several others operating at 500 to 700 pounds, per square inch, with a maximum steam temperature at about 725° F. Among engineers, there is a decided difference of opinion as to whether these 1,200 pound pressures are justified, the question involved being, whether or not the initial fixed charges for the higher pressure plant will be offset by the fuel saving. Further installations alone will tell the story, but it is probable that there will be, at least, some stations where the cost of the fuel and the load factors are such that these high pressures will be justifiable.

As mentioned above, the development of pulverised coal firing has stimulated material improvements in stoker design. These improvements have included the lengthening of the fuel travel through the furnace; the use of the clinker grinder for removing clinker automatically; provisions for more uniform distribution of the fuel throughout the length of the retort, and for the regulation of the air supply to the different compartments of the stoker. In connection with this last improvement it should be mentioned that, this distribution of the air to the different zones of the stoker is controlled automatically. All these changes are very promising in their possibilities of fuel economy.

In the north-eastern part of the United States there are a number of large public service power plants burning the fine sizes of anthracite coal. To burn this material satisfactorily, it was necessary to design a new furnace or rather to change the existing furnace by shortening the front arch and installing a long rear arch. Between these two arches, air is introduced to complete combustion. One of the purposes of the long rear arch is to deflect hot coal up towards the front portion of the furnace, and, thereby, to assist the ignition of the hard anthracite coal. The throat is designed to promote intimate mixing of the gases. A large combustion chamber is provided above the throat, as a space in which to complete the combustion. With such a unit no trouble is experienced with the ignition of the hard coal, and the losses, due to fine unburned fuel passing out of the stack, are reduced.

Control of combustion.

The development of automatic control of combustion of coal has been very marked in the last few years, and has made possible the maintenance of monthly operating efficiencies, very closely approaching the efficiencies found on test. The effect of this improvement has varied with the different plants, but, it is rarely less than one per cent., and an automatic control properly adapted to the requirement will, in general, show double this rate of saving.

Low-temperature carbonisation.

Another development, of particular interest to large central power stations, and especially those financially or otherwise connected with city gas-distributing companies, is the low-temperature carbonisation of coal before it is burned under the boilers. One large public utility electric company is erecting an experimental low-temperature carbonisation plant consisting of two rotary retorts, each 8 feet in diameter by 30 feet long. These retorts are heated by an oil-fired furnace, and re-circulated flue gas is used to control the temperature. In the first retort, coal is heated and oxidised to destroy some of the coking and swelling constituents of the coal. Balls or lumps of carbonised coal are discharged from the second retort.

A very extensive development of low-temperature carbonisation of coal has been carried out during the past year at the Lakeside plant of the Milwaukee Electric Railway and Light Company. This company is using powdered coal in its boiler room, and, in the experimental unit, the pulverised coal is pumped from the central grinding room to the carbonisation plant, where it is carbonised in falling vertically through two retorts in series. In this process, the pulverised coal is pre-treated by air and heat in the first retort, so as to render it non-coking and non-sticking. It then passes into the second retort where the volatile matter is distilled off and the coal carbonised, the coke being discharged from the bottom of the second retort. This coke is very friable and fine, is suitable for burning in powdered form in the boiler plant, and has a B.T.U. value per pound only a little less than that of the original coal. From each ton of coal so carbonised, approximately, 1,400 pounds of coke are produced. On very large scale operation, in plants having a fairly low cost of coal, it is quite probable that

this process will further reduce the cost of generation and power, quite materially. Under these conditions, a saving of one dollar per ton of coal carbonised is possible. This process will find its greatest development in large installations where coal may be obtained fairly cheaply, and, where the gas so produced may be disposed of to local gas companies distributing manufactured gas for domestic use. The development along this line at the Lakeside plant is being watched with considerable interest, since, in this particular plant, there is a possibility of a profit of a dollar a ton on the pulverised coke produced.

Steel industry.

Constant improvement in the operation of blast furnaces is taking place throughout the country. For example, at the Clairton plant of the United States Steel Corporation, one of the furnaces has been producing pig iron at the rate of 827 gross tons, per day, with the use of 1,825 pounds of high-temperature coke (produced at 2,285° F.), per gross ton of pig. When it is considered that this means a coke-pig ratio of 0.814, whereas, good practice is usually considered to be about 0.93, the importance and the possibility of fuel saving is obvious.

Throughout the steel industry, the attempt is being made to take into the plant only such coal as will pass through the coke ovens in the production of coke, and to use blast-furnace gas, coke-oven gas and coke breeze for the necessary furnace heating and steam raising. Many steps are being taken towards this end.

Automatic regulators are being used, wherever blast-furnace gas is being used, that is, on the stoves and in the boiler plant. These regulators are effecting considerable economy, thus making blast-furnace gas available for other purposes. Several companies are experimenting with electrical precipitation for cleaning the blast-furnace gas, thus enabling some of the sensible heat to be effectively utilised. At one of the large steel plants, waste-heat boilers have been installed to recover the heat in the exhaust from the internal-combustion blowing engines. These engines use blast-furnace gas, and is a good illustration of the extent to which, so-called, waste heat is gradually recovered.

In the open-hearth department the use of tar and coke-oven gas is being continued. There is a definite trend toward fire-tube, waste-heat boilers for open hearth work. This should mean greater efficiency since the air leakage will be less and the tubes easier to clean.

In coke plant, the trend is towards narrower ovens, higher temperatures, and shorter coking cycles, with greater coke production. The tendency, also, seems to be towards the use of ovens fired with producer gas from coke breeze, all surplus coke-oven gas being sent to the steel plant. In general, this will mean the concentration of producer gas generation in one central, continuously-operated plant, instead of in small, inefficient, semi-continuous plants, scattered throughout the steel mill as at present. The fuel used also will be a by-product of the ovens, and not raw coal as at present.

Throughout the steel industry, pulverised fuel is being used to an ever-increasing extent. For example, in the steel plant boiler room, pulverised coal is being adopted, during periods of blast-furnace gas shortage. Pulverised fuel is also being employed in continuous furnaces, bar-heating furnaces, nodulising furnaces, open-hearth furnaces, piled-scrap heating furnaces, etc.

Town's gas industry.

The gas industry, like the electrical industry, is undergoing a period of consolidation. With this consolidation into large, strongly-financed companies is coming a period of increased operating efficiency. Probably, the next few years will see a considerable increase in long-distance transmission of manufactured gas, from plants, conveniently located, either near coal mines or along the seaboard. During the past few years, there has, also, been a tendency towards slightly lower standards for heating, the present average being about 530 or 540 B.T.U.'s per cubic foot. The tendency, however, in this direction, has not been so rapid as was expected.

In installing new retorts, the practice appears to be towards the cell type of by-product coke oven. Many manufactured gas plants are installing waste-heat boilers, to a considerable extent. In one of the large plants

in the country, steam is being generated through the dry quenching of the coke, by the Sulzer system. Operating data from this plant is as follows :—

Average power consumed, per day, for fan	858.1 kw.-hours.
Average „ „ „ hoist	82.8 „ „
Average temperature of feed-water	119.3° F.
Steam pressure developed	139 lbs. per sq. in.
Coke charged, per day	729,400 lbs.
Temperature of hot coke, to inlet to quencher	1775° F.
Steam produced under above conditions, per thousand pounds of coke, cooled	402.6 lbs.

Improvements are not only being made in the production of steam from waste heat, but economies are also being introduced in the use of the steam. To this end, a number of plants are installing steam accumulators in connection with the generation of carburetted water gas. Substantial economy is being, thereby, effected.

Another device, illustrating the extent to which the gas companies are intent upon saving fuel and being less of a nuisance to their neighbours, is the centre feeding of by-product coke ovens with steam suction jets installed in the off-takes. Coal is charged to the centre-feed and suction is applied to the gas off-take. In this way, the gas that normally escapes when coal is being charged is saved, resulting, not only in economy, but also eliminating a serious nuisance.

Tests, conducted by the American Gas Association, during the past year on three gas plants, show the following results:—

Plant location.	Type of plant.	Lbs. of coke per ton of coal charged.	Cu. ft. of gas per ton of dry coal charged.	B.T.U.'s per cu. ft. of gas.	B.T.U.'s required per lb. of coal coked.*
Lowell	"D" Type.	1,371	23,800m.	542	1,515
Utica	Becker (Cell Type)	1,404	22,240m.	584.2	1,689
Rochester	U.G.I. (Intermittent Vertical)	1,414	22,300m.	540.0	1,755

*Total heat to the gas producers, minus credit for waste heat steam.

Domestic heating.

In considering domestic heating in America, it should be remembered that practically all homes are heated from an individual central heating plant. This central plant may distribute either steam, hot water, or hot air to the various rooms. It should also be remembered that labour costs in America are high and that only the wealthier people have servants. Up to the present, anthracite coal, carefully screened, and of large size, has been the main fuel used for domestic heating, although a large quantity of low-volatile, bituminous coal has, also, been used for the same purpose. In view of these conditions, it is apparent that any development which will give automatic and an even heat to the home would be welcome. Such automatic heating is being provided particularly by the introduction of small household oil burners. Manufactured gas is, also, being used, to some extent, although in most cities the price is still so high as to render it prohibitive for the average family. Small automatic air-blown stokers for burning the small sizes of anthracite coal are also being used to a considerable extent, but the greatest development has occurred in the use of oil for the reason that stokers, for household furnaces, are not entirely automatic, but have to be tended at least once or twice a day, and gas, although easily operated automatically, is too expensive.

Oil burners have been so developed that they are much more efficient than formerly, and, comparatively, noiseless in operation. They produce but little smoke and soot and are, practically, as clean as gas burners.

Heat is saved, not only by the proper proportioning of air and fuel which effects a very great saving indeed but, also, by not over-heating the house in Spring and Autumn when the weather changes very rapidly. Furnaces,

as a result of this development, are being more carefully designed, with tighter doors and with more heating surface, for picking up the heat from the hot flue gases. Even economisers are now being used, for the purpose of improving fuel economy when oil is being burned. In general, the average efficiency of a coal-fired domestic furnace, with the lack of attention it usually suffers from, is, probably, not over 50%. Numerous tests on oil burners for this work show efficiencies ranging from 65 to 73 per cent. Gas-fired hot-water boilers vary in efficiency from 78 to 84 per cent., while gas-fired hot-air furnaces have shown efficiencies as high as 90 per cent.

The development in automatic heating has been very extensive, and at the present time, nearly one million oil burners are installed in the United States. It is estimated that, over one hundred and fifty-thousand additional oil burners will be installed in homes throughout the United States during the coming year.

Lime industry.

The lime industry may be mentioned, as another example of the extent to which improved furnace operation is being carried out, in all industries using coal. Operations in this industry have in the past been very wasteful. To-day, there is a definite trend away from the small hand-fired furnaces towards large units, producing two or three times as much lime per day, and with greatly improved furnace efficiency. The furnaces of the large lime kilns are fired, either by automatic stokers, or, with producer gas made from soft coal. Automatic temperature regulation is being tried out, successfully, in a number of plants. The wastefulness involved in using a large excess of air to modify the temperature, and to avoid overburning of the lime is now being recognised, and to prevent this waste the use of re-circulated flue gas is being tried out in a number of plants. The result is better fuel economy and a higher grade product.

Oil refineries.

The modern oil refinery is a large user of fuel. For example, one moderate-sized oil refinery uses over a million and a quarter dollars' worth of fuel each year. Another very large oil refinery uses over fifty million cubic feet of natural gas, per day, an amount equal (in B.T.U.'s) to that consumed by a very large city. In times past, cracking-coil furnaces were fired with a large excess of air, in order to prevent burning out the first row of tubes, which are exposed directly to the radiant heat of the fire. To-day, various methods of firing with a very small excess of air are being used. One of the most common of these methods, employs a furnace fitted with carborundum muffles. These mufflles absorb heat from the gases at their higher temperatures, and then radiate it to the coils at a temperature lower than the flame temperature of the fuel. The gases after being thus cooled to temperatures below the danger point (by radiation from the muffles), are discharged from them and pass around the coils, as in other furnaces. More efficient use of the gas produced within the refinery is, also, being made.

Miscellaneous.

As an example of the extent to which the people of this country are interested in fuel economy, and in the abatement of smoke, may be mentioned the efforts of the Citizens' Smoke Abatement League, of St. Louis. This organisation, by the able management of engineers, and with the hearty support of some of the most prominent citizens of that city, have raised $250,000 to be used in a three-year campaign for the abatement of smoke in St. Louis, and to provide furnaces and fuel, more suitable than those at present in use.

Some little interest has been manifested in the use of powdered coal in the merchant marine and in experimental work, with Scotch marine boilers, as many as 80,000 B.T.U.'s per cubic foot of combustion space have been generated. Large scale experiments are now being conducted along these lines.

As another example of the increase in fuel economy in the United States, may be mentioned the production of natural gas gasolene. Up to 1915, practically all of the natural gas produced in this country (600,000,000,000 cubic feet, per year), was burned without scrubbing the gas, for its gasolene content. To-day, with a production of natural gas about double than in 1915, over 90 per cent. of the gas is being scrubbed, or, treated for the recovery of gasolene, with the result that 1,100,000,000, gallons of gasolene are being produced from this source. This amounts to approximately 12 per cent. of the total gasolene production of the country, and is a material, the real value of which was wholly wasted less than 15 years ago.

FUEL ECONOMY MEASURES IN FRANCE.

By M. Pierre Appell.

(*Administrateur delegue de l'Office Central de Chauffe.*)

Since the war, France has experienced serious difficulties in the maintenance and allocation of her fuel supplies, and consequently has had to make considerable efforts to reduce fuel consumption without decreasing industrial production.

In this article, an attempt is made to indicate the work which has been done in this direction and the results obtained.

Organisation of work on fuel economy in France has been effected, first by the works themselves, and, secondly, by organisations outside the works.

Fuel economy bureaux in French works.

The organisations for the improvement in the utilisation of fuel in works varies considerably in different establishments. In many cases, little or nothing has been done. The director, or engineer in charge of the plant, may give the subject casual attention, although he has not always the necessary experience or ability.

In some large establishments on the other hand, particularly in great industrial groups, special fuel departments have been formed, details of a few of which may be given as illustrations of the work that has been accomplished, and as indicating future possibilities.

At the Creusot works, a very complete organisation is in operation, consisting of a section dealing with industrial heating, a supervisory staff for boiler and producer plant, and a research laboratory. The functions of the section of this organisation dealing with industrial heating are as follow* :—

(1) The preparation of programmes of fuel consumption in various departments of the works.

(2) The control of fuel supplies both from a point of view of weight and quality.

(3) Distribution of fuel according to its quality, to different portions of the plant in order to ensure that suitable types of fuel are supplied for the various operations.

(4) A study of the best type of plant, when new furnaces are required, in conjunction with the officers of the metallurgical and development departments.

(5) Drafting of enquiries and specifications issued to the leading French constructional engineers, and comparative study of propositions submitted.

(6) After the installation of the furnaces, the supervision of efficiency tests, in the presence of representatives of the constructional engineers, with a view to verifying the realisation of guarantees of production and fuel consumption.

(7) The study of existing heating plants, and consideration of suggestions for change or replacement by more modern or more economical plants.

(8) The selection of measuring and other apparatus for the scientific control of furnace operation.

(9) Collection of technical information published in French and foreign scientific periodicals, co-ordination with work of constructional engineers or inventors of processes and plant, and visits to factories or establishments using new apparatus or new methods of heating.

This Department is quite independent of the manufacturing side, and is controlled by the chief engineer in charge of metallurgical research, who is directly responsible to the directors. The head of the fuel department is an engineer who is assisted by the necessary staff.

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*These examples were given by M. Mahler in the report on the Organisation of Fuel Economy in Industry, made for the Inter-ministerial Committee of Utilisation of Fuel. Several passages in the following pages are taken from this report. (See *Chaleur et Industrie*, September and October, 1922).

The department works in collaboration with the central laboratory, which possesses the necessary apparatus for fuel analysis, determination of calorific power, pyrometer determinations, apparatus for measurement of gas volume and velocity, and so on, which apparatus is in the hands of assistants who have received the necessary scientific training.

At the works of the Societe des Forges et Acieries de la Marine et d'Homecourt, an organisation for fuel economy has been established since 1912. It was described by M. Theodore Laurent in the "Revue de Metallurgie," 1919. This organisation consists of :—

(1) Sectional departments, whose duties are to purchase, use and keep in good condition, the measuring instruments required, to make such tests as are required on the furnaces under the supervision of the technical heads of departments, to compile complete technical reports on the use of fuel in the works, and to issue to the central office daily reports of consumption of fuel and production of each works.

(2) A central department, whose duties are to ensure liaison between the sectional departments, and to centralise information on the utilisation of fuel in the works, and to assist the directorate generally in the control of fuel consumption, particularly by comparison of results obtained in the various works.

It is to be noted that the department of fuel economy only acts in an advisory capacity to the manufacturing departments which still retain complete responsibility for production in all its branches.

In the Etablissements Constructeurs de l'Artillerie, 15 in number, with a total annual consumption of coal and coke of the order of 60,000 tons, an organisation on the following lines has been established.

In each establishment, a special department of fuel economy has been formed, whose activities are followed and controlled by a central department. The functions of the local departments are to obtain, to instal, and to maintain apparatus for fuel control ; to study plant operation in collaboration with the technical head of the department involved, so as to determine the most efficient methods of operation; to control the fuel supplies, and to allocate distribution among the works, to determine the consumption of various sections of the plant; to study the best methods of distribution of premiums for economies in fuel utilisation; to file information on all questions concerning fuel consumption, and to study such improvements or modifications as would tend to reduce consumption.

The work of the central department follows the same general principles as the local departments. Essentially, it effects a liaison between the staff of the various establishments controlling fuel consumption, and correlates and distributes reports and information received from them and other sources. It compiles periodically, from information available, thermal balance sheets indicating the efficiency of plant. This organisation has given very appreciable results.

Organisations outside the works.

Works organisations whose functions are of the character described above are very useful, but there is some risk that their activities may remain in obscurity. Each concern is only able to profit by its own experience, and is not informed of the work done by its neighbours. It is obvious, therefore, that bodies extraneous to the works should be set up to study the problem as a whole, and to render help to all industrialists. An Inter-ministerial Committee for the Utilisation of Fuel formed by the Ministry of Public Works has published very interesting reports.* This Committee in 1923 promoted a Congress of Industrial Heating, which helped considerably to promote research on the subject, and in the publication of results obtained. A similar congress will be held in 1928.

A Society of Industrial Physics has also been formed for the purpose of continuous research. At the Town Hall, Paris, a Committee of Fuel Economy has been formed, for the purpose of investigating the question from the points of view of domestic and town heating, and to disseminate propaganda among

*The list is as follows: Production and Utilisation of Steam (M. Kammerer), Present-day Technique of Boiler Plants (M. Rauber), Fuel Economy in the Railway (M. Loviet), Utilisation of Wood in Industry (M. Metayer), Organisation of Fuel Economy in Factories (M. Mahler). These reports have appeared in the Official Journal.

the public. Other organisations dealing directly or indirectly with the more rational utilisation of fuel are the Direction des Recherches Scientifiques et Industrielles et des Inventions, the Station d'Essais du Comite des Houilleres and Comite Central des Cokes de France, but these bodies do not directly act for individual works, and the Office Central de Chauffe Rationnelle, and Les Associations de Proprietaires d'appareils a Vapeur, are the only two bodies which act as direct advisers to industrialists.

The Office Central de Chauffe Rationnelle was formed in 1919, when the fuel crisis was particularly acute, for the purpose of assisting industrialists to effect economies in fuel. The initial capital was subscribed by groups of armament firms directly interested in the coal industry, with the aid of a subsidy granted by the Government. In order to ensure flexibility, the form chosen for the organisation was that of a limited company, but in consideration of the disinterested character of the work undertaken, the articles of association prescribed that all profits beyond 6 per cent. of the capital invested should be used for research and investigation, or for scholarships at the School of Industrial Heating. This office has initiated the following activities :—

(1) A school of industrial heating giving courses of instruction suitable for engineers who have already had an extensive technical training, which would give them the supplementary knowledge necesary to allow them to qualify as fuel engineers. Further courses have been established for works' foremen, with a view to qualifying them as heads of boiler plant, furnace plant, or producer plant. The courses are essentially practical, and include training in the use of apparatus for measurement and control, and also the preparation of thermal balance sheets from data available. The length of the course is reduced to a minimum—five weeks for engineers, and four weeks for foremen.

(2) A centre for collecting information and for research. By this means the office is kept informed of progress made in industrial heating in France as well as abroad; tests of new processes are carried out, and liaison with similar bodies abroad is effected.

(3) A special laboratory for the study of fuels and combustion. This laboratory analyses and determines calorific values of solid, liquid and gaseous combustibles, analyses flue gases, boiler feed water, and generally studies all chemical and physical processes bearing on industrial heating. Among its functions are the regulation, standardisation and improvement of apparatus for the control of heating systems, and in collaboration with other laboratories comparisons are made of methods of fuel analysis with a view to their standardisation. Junior chemists are trained by the laboratory, in the work of testing and analysis of fuels.

(4). Works' visits. Engineers of the office, when requested by industrialists, visit various works with a view to studying on the site, questions relating to the utilisation of fuel. Their investigation includes detailed examination of various apparatus for the production or utilisation of heat as well as the general organisation of the works from the point of view of the character of fuel used, and so on. The expert knowledge available in the central office with respect to all types of plant (boiler plant, furnaces, gas producers and so on), is of particular advantage in that it allows of the examination of fuel problems in their entirety.

Consequent upon these works visits, detailed reports are sent to the industrialists concerned, giving the results of observations made, with thermal balance sheets, and advice is given regarding the measures desirable to secure economies, with special reference to the economic importance of these.

(5). A department for industrial investigations. This department examines for industrialists, changes desirable in works' practice to secure fuel economy, and examines possibilities of improvement by the installation of new plant.

The closest liaison is effected between the different departments of the office, and their work is continuously correlated. The collaboration existing between the school, the research and information centres and the works' visits department, is a characteristic feature of the institution.

Independently of the work of training personnel, technical research and its activities in the role of adviser to industrialists, the office carries out active propaganda with a view to developing a desire for fuel economy in the country, and in this connection publicity is given to the results of investigations of its engineers and public conferences. Exhibitions are also organised.

Economies effected at different works, either by inauguration of a staff for fuel control, or by investigation of plant used, vary from 10 to 25 per cent. of the fuel consumption. In certain exceptional cases, by the installation of suitable gas producers and furnaces, these savings have reached 60 per cent. Generally, economies have been obtained as much by a better control of existing apparatus as by improvements in the details of plant used. Additional to the reduction of fuel consumed, a supplementary economy has frequently resulted by the adaptation to the plant of a less costly fuel. It is difficult to estimate economies that have been obtained by rational study of individual plants as a whole. In some cases, results might be more far reaching than would be possible, simply by improvements in operation.

The first association of steam users formed in France was that of the Association de Proprietaires d'Appareils a Vapeur at Mulheim, in 1867. Its aim was defined in the first clause of its articles of association as, to avoid accidents and boiler explosions, and to influence its members to a more economic production and utilisation of steam. The same object has reappeared in the statutes of other organisations formed successfully at Lille, Paris, Rouen, Lyon, Amiens, Bordeaux, Nantes, Rheims and Marseilles.

The activities of these associations developed primarily in the direction of security. Public bodies appealed to them more and more for help, and by a decree, in February, 1919, they were given power to certify boilers from the point of view of safety.

In addition, however, to regular boiler inspection for their members, with particular reference to investigating explosion risk, these associations also carry out considerable technical work in connection with the economy of fuel in the production and utilisation of steam. This work involves preparation of indicator diagrams of machines, of steam tests for boilers, etc.

The development of the various associations has been somewhat unequal from this point of view, some of them having set up laboratories and organised a special fuel economy section, whilst others have contented themselves with giving general advice on questions of fuel economy in the course of the periodical visits paid in regard to security.

Results obtained.

The results obtained by the organisations dealt with above are very appreciable, but it is certain that further important economies of fuel will be realised when the education of the manufacturer is more complete, and when he is better able to understand how much it is to his interest to follow lines suggested as the result of investigation by the societies concerned.

FUEL ECONOMY IN GERMANY.

By Dr. K. Rummel

(*Fuel Economy Bureau, German Iron and Steel Association*).

The situation in Germany in regard to coal supply after the war was very unfavourable. The greater portion and the best of the coal mines of Upper Silesia passed into the possession of Poland, while France obtained the coal mines of the Saar district, and under the Versailles Peace Treaty, large deliveries of coal to former enemy countries had to be made by Germany for a large number of years. For a prolonged period, these relations produced conditions under which the quantity of coal available for German requirements was less than two-thirds of the pre-war supplies, and German industry, therefore, was without sufficient coal for its maintenance. The lack of capital prevented the increase in the supply by sinking new coal pits, on the one hand, as well as the importation of foreign coal to make good the deficiency, on the other. In order to avoid a large reduction in the output of manufactured wares and, thereby, to weaken, further, an already precarious state of industry, and, at the same time, to prevent any critical increase in unemployment of the German population, it was essential that the most suitable use of the fuel available should be made, and this with the greatest economy.

As with all great economic problems in every country, the question arose as to the respective parts to be played by the State, and by private initiative, in the organisation of measures of economy. It was clear that in the very difficult position brought about, it was impossible to carry out the necessary means without the active support of the State, and also, that State efforts alone would lead only to a prolonged delay in righting the situation. It was sought, therefore, in addition to calling on the State for assistance, to utilise, as far as possible, the private resources of commercial and industrial enterprises.

The production of coal, and the question of prices in the fuel trade, were controlled by the State through syndicates, regulated by the heads of the State Coal Association (Reichskohlenverband). Further, the State Coal Commission was constituted as a central body of a chiefly advisory character, representative of all the different interests concerned, for the exchange of ideas, and possessing a certain amount of authority on vital questions.

The distribution of coal also was vested in a State Coal Commissioner (Reichskohlen Kommissar), who possessed dictatorial powers.

The application of methods of fuel economy was entrusted to the private Technical Associations, and a number of independently-formed bodies acting, of course, in conjunction with existing organisations. The State took no direct part, except in the direction of advancing such endeavours, and, in the formation of a Committee, from the expert members of the State Coal Commission, which functioned in an advisory capacity.

The procedure, under the arrangements referred to, differed from those adopted in most other countries. In the majority of cases, as long as no compulsory distribution rules are in force, the preliminary work of engineers, contractors, and even the smaller business concerns, permits an economic calculation to be made in the cases of new construction works and other special purposes, according to the relative importance of the costs. In Germany, however, under the conditions mentioned, the technical problem was much more than one of using a given quantity of fuel to satisfy the requirements of the population, and of obtaining the greatest possible production from industry. Extensive re-building, or new construction, as well as the introduction of new manufacturing processes, could only be undertaken in the rarest instances, on account of great money scarcity and the very heavy rate of interest.

While, therefore, other countries were building great power plants, and developing their factories on modern lines ; while, for example, in these countries, new boiler types and new processes for power production were being introduced (for instance, pulverised fuel firing), it is only in the last two or three years that Germany has been able, slowly, to follow these movements. First and foremost, came the cry of economy ! economy ! and this, indeed, in the face of a very modest national revenue.

The most important result of the economy measures adopted was the saving of fuel in industry, transport, and electrical undertakings. Their relative fuel consumption amounted to about 85 per cent. of the total. The iron industry formed a heat economy centre under the title of the " Warmestelle Dusseldorf," and this example

was followed by the mining industry, the State railway administration, and other industrial groups. The existing Steam Boiler Inspection Associations (organisations of a semi-official character, concerned mainly with the safety of steam boiler plants) also worked in the same direction and for the same purpose. As a central organisation for the technical and economic campaign, a principal centre for heat economy (Hauptstelle fur Warmewirtschaft) was formed, with headquarters in Berlin. Simultaneously, also, a stronger basis was created for these movements in the development of the idea that every large works should have its own Heat Economy Department, or, at least, a heat engineer, for carrying out the task of fuel saving. This latter step, proved to be the most important of the whole organisation. It is true, that it immediately became apparent, that there existed a lack of qualified men for the work, and the first consideration was to train engineers and technologists, to organise instruction courses and methodical teaching, to provide educational material, and to organise propaganda by means of the distribution of technical-economic literature.

A special feature in the formation of Heat Economy Departments of the several industrial works, was the necessity of bringing such organisations under the leadership of the Head Management, and only, in exceptional cases, could they be incorporated in already existing Departments. This idea proved a great success, not only in a fuel economy sense. It is an important principle of modern works' organisation, that the different sections within the works should operate on parallel lines, so that the responsibility becomes divided. Special duty lists are provided for each section and co-operation of the different sections for the satisfactory working of the whole of the operations, is enforced.

The heat economy centres formed, at that time, have performed good service up to the present. They exist to-day, after the coal scarcity has disappeared, and form the heat economy working cells of the body of industry. It is true that many of them have, in the course of time, also undertaken other economic tasks.

According to the size of the Works, the heat economy centres have different degrees of importance. In the smaller factories, often a single technologist is sufficient for the work required, while in the largest Works there are special heat economy departments, the personnel of which may number up to 80 persons, including mechanics and the men for operating installations, insulating columns, etc.

The actual heat economy work is conducted by these local centres. The large collective industrial heat economy centres, such as the " Warmestelle Dusseldorf," which covers the whole iron industry, do not carry out the details, but function to stimulate, advise, collect, arrange, and publish useful material, and in all doubtful cases to supply information regarding experience obtained elsewhere. Visits to works are made periodically and, in suitable instances, particularly where problems of general interest arise, investigations are made by their highly trained personnel. All matters of special importance are fully discussed, by practical experts.

Science of measurement.

A most important function of these heat economy centres is the development of the science of measurement, measuring methods generally and instruments, the maintenance of the instruments, and the interpretation of the indications yielded by them. The largest works take up to 400 of such indications daily. One of the first heat economy tasks consists in close observation of all heat-consumption points ; for this purpose, instruments are necessary, and these are usually of two descriptions. For the workmen it is sufficient to have a direct reading instrument, without registration, but for the engineer, an instrument is required which will provide graphic indications and will show the working conditions for a whole day, or, even for longer periods. It is not always possible to obtain the two kinds of indications from the same instrument. A third form of instrument is concerned, chiefly, in the collection of statistics. Such instruments are generally of the counting type, and are quite different in character from those referred to above. These yield end results daily, weekly, or monthly, and provide data which can be applied in the calculation of the working costs. The careful collection of statistics, and the supply of extensive information of other descriptions, bearing on production costs, are important duties of the heat economy section. A fourth type of measuring instrument, is that used for scientific research, which, naturally, is required to give results with great accuracy. This is not, usually, a permanent installation. Instruments of the four types referred to have been developed conscientiously in Germany by a number of first-class firms, who have brought the science of measurement to a high standard, and have designed instruments which will perform satisfactorily under very difficult working conditions.

There is, of course, no sense in installing a large number of instruments in a works which are entirely out of date, with the idea that this is all that is required to effect a fuel saving. A highly developed science of measurement demands very careful watching, by both mechanics and officials, for the inspection of the correct working, and for working-out, and for the utilisation of the results.

The best instruments are useless, if they do not lead to a permanent improvement of working results, and, for this purpose, co-operation, between all parties concerned, is required.

The instruments now employed for checking industrial operations have developed from the simple indicator up to those which give a graphic record ; from the semi-automatic signal apparatus up to the self-acting control of firing. On the other hand, the semi-automatic apparatus is led into great regulating centres, which are in commanding positions, and by which, day and night, a workman, or, in important cases, an engineer is stationed. These are equipped with a switchboard-like regulator, and form the heart of the works' economic body, from which the total distribution of the heat and energy takes place. Distant transmission and distant registration, thus play an important part.

The high status of the science of measurement in Germany, is only the result of years of working in the field of heat economy. In the early days, the fuel-saving problem was, comparatively, simple, and consisted in applying all measures generally known, but by no means generally practised. It was then revealed that a long distance had to be traversed before every workman, every master, engineer, works' manager, and contractor would use all means within his power to carry out and apply the teachings of science and technology. A simple example is found in the use of exhaust steam from non-condensing steam engines. In every land, to-day, are large numbers of such steam machines, and numerous cases where, for example, the waste steam of feed-water pumps is not utilised to preheat the feed-water, or, where the exhaust steam from hammers is not used in winter, for the heating of workshops and offices. Further, there are not a few cases where the electrification of a plant has been carried out to such an extent that special steam-producing plants for heating and hot-water supply have had to be installed. In every land, for room heating in industrial plants, may be found central heating installations, or, even the heating of individual rooms with stoves, fed with coal or coke, instead of converting the fuel to steam and utilising the exhaust for heating requirements. It is generally recognised that such steam-heating installations are extremely economical, and that, on an average, they recoup their capital cost in a year or two.

Notwithstanding this fact, in few works is the trouble taken to ascertain how much coal is used for the heating of workshops and offices, but carefully compiled statistics have shown that large quantities of fuel are thus consumed.

In this sphere, also, belongs the utilisation of the waste heat from furnaces and gas engines for steam production which, in many cases, would be profitable. The steam, which could be produced in waste-heat boilers in Germany, would suffice for the generation of over 100 million kilowatt-hours, per annum.

There are still simpler means to heat economy. To these belong, for example, the constant overlooking of the steam traps which form a constant source of heat loss. It is not sufficient merely to establish this fact : the maintenance work, in this connection, requires a working organisation, equipped with special knowledge and judgment, and, further, an " overlooking of the overlookers " is demanded.

It is similar, in carrying out the efficient insulation of all steam-conducting pipes. It is necessary, only, to inspect a works with observant eyes, to discover a whole series of items requiring attention. In such cases, it is less scientific and heat economy experience that is needed, than a methodical and cleanly way of conducting the work. The expression " cleanly " is to be taken literally, for, in large numbers of undertakings in all parts of the world, care, in this direction, is lacking.

A self-evident fact, often disregarded, is that firing must be carried out with a suitable fuel ; and, at the same time, the cheapest fuel, which is applicable to the purpose, or, if the fuel conditions cannot be altered, then the firing must be adapted to suit the fuel. In such cases, it is usually necessary to apply some kind of lever, if heat economy is to be obtained ; indeed, it is a task, the solution of which is possible, only through co-operation between the producer and the consumer. Only thus, can the most favourable utilisation of the fuel supplied be obtained ; only thus, can national fuel economy be carried out on an appreciable scale—above all, only thus, can suitable employment be made of the less valuable fuels.

When this aspect of the fuel question is solved, one proceeds to the correct adjustments of the firing and the power machines, thence to the training of the personnel, or, in a word, to the " overlooking."

There is no sense, however, in equipping a crude and primitive works with expensive and delicate measuring instruments, or, to enter upon extensive scientific investigations, before all the minor matters have been rectified. The co-operation of the heat engineer, in such simple tasks of works' organisation, however, never ends in the largest and best works, and extends far into refinements ; as, for example, up to the treatment of the energy balance through the skilful conduct of the manufacturing process. The problem, then, is to reach a uniform loading of the boiler plant, distribution system, gas generators, and other gas providers. It is in this sphere, that great economies in heat may be made.

All technical arrangements, from the heat conservation point of view are, in a great measure, dependent on the heat consumption, on the character of load curve, but, more particularly, on the pauses in operation. Continuous working with a uniform load, is a very important requirement for satisfactory heat economy and, generally, for effecting a saving in working costs.

The heat economy question tends here to pass over to the general works' problem, and, one can even say that, fundamentally, heat economy is nothing more than a small part of the so-called " working economy," a section of the sphere of " works' management."

Influencing factors.

Large-scale heat economy is possible only if, at the same time, the whole of the subsidiary operations are carried out in accordance with the highest economic principles. A single example, out of many, may suffice. In a forging furnace, the first consideration is not that of obtaining the smallest consumption of fuel. The quantity of the output, the most suitable duration of the heating, the influence on the quality of the forged material, the raising of the performance of both furnaces and hammers by suitable means, the relation of the size of the furnace to the existing hammers, and a whole series of other questions are much more important than the fuel consumption. Thus, one moves gradually from the initial stages of heat economy, that is, the hunt for the calorie, over to " working " economy.

Another extensive field of application for the heat engineer, is in the treatment of those technical processes which, on the one hand, are connected with the manufacturing method, and, on the other hand, with heat and power economy, and where physical and chemical influences on the treated material are, simultaneously, bound up with heat transmission and power consumption. Quite apart from fuel consumption, there occur here many considerations of importance affecting the extent of production and the quality of the products. The solution of such problems can be effected by the joint action of the works' engineer and the heat engineer. A knowledge of heat and measurement technique is involved, which is not possessed, in a sufficient degree, by the average works' engineer, and co-operation between the works' engineer and heat engineer will be of considerable advantage.

To this sphere belongs, for example, the whole field of the production and working of iron, steel, and other metals ; the manufacture of ceramic products ; the burning of limestone, and many other industrial operations.

Scientific investigation.

We are now in the sphere of scientific investigation, and it offers wide scope for activity. We are, even to-day, without knowledge, in many cases, of the basis of combustion processes, and the utilisation of heat. For example, the combustion of a fuel is still an empirical process ; the flow of the flame through a fuel layer ; the behaviour of heat through convection and radiation still present many unsolved problems. The measurement of very high temperatures, particularly gas temperatures, is still very difficult, and much more difficult than the uninitiated might suppose. Temperature measurement errors, in practice, are regarded as a matter of course and, under certain circumstances, may amount to several hundred degrees.

The behaviour of different materials, for example, refractory material, at high temperatures, requires extensive study. The resistance to the passage of gases and air in boilers and furnaces, cannot be calculated accurately, and, indeed, we have no formulae for the resistance in gas conduits, under not quite simple

conditions, which meet the demands of practice. The distribution of the velocity of a gas stream of large dimensions over the section is extremely important, but we do not know it. The process of combustion, under practical conditions as, for example, the combustion velocity of gas mixtures, is known, only under laboratory conditions, and we are still without sufficient knowledge for applying these to practice. This applies, in particular, to the catalytic action involved in the chemical process of combustion. The action of bright luminous flames is known to us, only in quite small measure. The calculation of the true temperatures of the flame, entering a combustion chamber, is still hardly possible. The boundary between selective and instantaneous combustion has not been fully investigated. The heat storage process in masonry, as for example, in regenerators, we can only slightly comprehend. Our knowledge of the constitution of coal is very defective, notwithstanding that a series of scientific works thereon are in existence. We do not know how the coal burns ; indeed, we do not know whether primary combustion yields carbon monoxide or carbon dioxide, quite apart from the endothermic and exothermic reactions which take place during the process of coking. These are all questions, whose solution would be of great service in practice.

In addition to the scientific problems, are subjects demanding practical observation, of which a few may be named :—Pulverised coal ; high-pressure steam ; superheated steam ; air preheating ; low temperature gasification ; hydrogenation ; gas transmission over long distances ; developing greater units ; regulating processes ; energy storage ; electric current supply ; the production of " white coal," etc.

This is a work, which is not the prerogative of any particular nation, nor to be pursued with a view to meeting the particular requirements of individual countries. It belongs to the sphere of international co-operation and exchange of experiencies. It is true that, these problems are so many and so varied that this co-operation cannot be achieved by simple means. Conferences, such as the London World Power Conference do not suffice. If an impetus in this sphere is to be created, it should take the form of a World Conference, but a conference limited to a single section, in which only one of the important problems, referred to, would be treated by the greatest experts of all lands. The more such sectionalised Conferences are arranged, the more marked will be the results obtained.

FUEL ECONOMY IN BELGIUM.

By Prof. P. Erculisse.

The fuel resources of Belgium consist chiefly of coal deposits ; near these are found strata of peat, which have a certain importance but have not yet been exploited.

The resources of the Congo appear to be more considerable and more varied, but, up to the present, they have played no part in the politics of fuel in this country.

The Belgian coalfields may be divided into two groups : the Northern group situated in the Campine ; and the Southern group, which includes the oldest and the largest number of collieries of the country. This group comprises the districts of the Borinage (a region stretching west from Mons), of the Centre (situated between Mons and La Louviere), of Charleroi, Namur and Liege.

The production of the Southern group of mines for the years 1913 to 1925 was as under:—

	Metric Tons.		Metric Tons.
1913	22,841,590	1923	22,114,990
1921	21,427,880	1924	22,255,360
1922	20,780,430	1925	21,993,100

The production of the Northern or the Campine group was :—

	Tons.		Tons.
1917	11,640	1922	428,070
1918	65,670	1923	807,650
1919	139,930	1924	1,106,500
1920	245,760	1925	1,103,930
1921	322,530		

The difference in the quality of the coal produced was very marked, in the different districts.

In the district of the Borinage, which produces, from its 15 collieries, about 4,500,000 tons, a certain number of mines produces high volatile coal (charbon Flenu) yielding from 25 to 35 per cent. of volatile matter. This is the case in the collieries of the Grand Hornu and Wasmes, while the other mines yield only charbon gras (22 to 25 per cent. of volatile matter), demi-gras (17 to 22 per cent. of volatile matter) and even $\frac{1}{4}$ gras (14 to 17 per cent. of volatile matter).

In the district of the Centre, which possesses eight collieries providing 4,023,095 tons, those of Maurage and Bray produce coal with 25 per cent. of volatile matter, the others produce charbon gras and demi-gras coal.

In the district of Charleroi, where the output is more than 10,000,000 tons, the coal produced is classified as anthracite, dry, quart-gras and demi-gras. Coal which yields more than 15 per cent. of volatile matter is rare.

The Namur district is of no great importance, the output in 1925 amounting to only 264,784 tons, yields a coal similar to that of the Charleroi district.

Finally, the district of Liege, which comprises 36 collieries, and where the output is nearly 5,000,000 tons, produces, with few exceptions, very dry and anthracite coal.

The district of the Campine is being thoroughly exploited. The collieries there are very up-to-date, and the output is much larger than that of any other district. It appears that the coal from the fields of that region, are much richer in high volatile coal than those of any other district.

According to the Reports of the Mines, the distribution of coal produced in, per cent. of the whole was, in 1913 and 1925 as under :—

	1913.	1925.
High Volatile	9.2	15.3
Gras	23.9	18.0
Demi-gras	42.6	44.6
Dry	24.3	22.1
	100.0	100.0

The increase of the percentage of high volatile coal from 1913 to 1925, is due to the greater exploitation of the district of the Campine.

Another characteristic of Belgian coal is that, it produces a considerable quantity of dust. In order to utilise this dust, and to make it of value, it is compressed into briquettes, using about 10 per cent. of pitch as a binder. The production of briquettes in Belgium is shown in the following table :—

	Metric Tons.		Metric Tons.
1913	2,608,640	1923	1,929,269
1921	2,676,680	1924	2,030,310
1922	2,497,350	1925	2,237,171

As will be seen, the briquettes represent about 10 per cent. of the total output.

The production of coke is given in the following table :—

	Metric Tons.		Metric Tons.
1913	3,523,000	1923	4,179,964
1921	1,402,610	1924	4,216,980
1922	2,849,994	1925	4,111,170

In regard to the production of gas for lighting purposes, it may be estimated at, about, 350,000,000 cubic metres.

Fuel supply and requirements.

It may be of interest to determine, whether the production of the country is sufficient for its needs. To arrive at this we have only to compare the exports and imports. These have been for the years 1924, 1925 and 1926, as under :—

I.—RAW COAL.
(*Metric Tons.*)

Year.	Imports. Metric Tons.	Exports. Metric Tons.	Excess of Imports over Exports. Metric Tons.
1924	9,226,614	2,138,642	7,087,972
1925	8,669,334	2,550,405	6,118,929
1926	7,756,061	3,735,096	4,020,965

As will be seen, the result is a deficit. Large proportion of the imports come from Germany, and a considerable part from Great Britain. The exports are sent, chiefly, to France.

II.—COKE.
(*Metric Tons.*)

Year.	Imports. Metric Tons.	Exports. Metric Tons.	Excess of Imports over Exports. Metric Tons.
1924	2,367,535	785,980	1,581,545
1925	2,338,707	848,458	1,490,249
1926	2,609,906	766,624	1,843,282

The situation is the same here, as for raw coal, imports coming from Germany and Great Britain, and exports going to France :—

According to statistics, published by the "Corps des Mines," for the year 1925, blast furnaces absorbed 2,576,917 tons of coke, of which 2,080,218 tons are obtained from the coke ovens of the country. It is evident that a considerable quantity of coke is used for other purposes, than those of metallurgy. It is necessary, further, in Belgium to carbonise coal in order to produce tar and, consequently, pitch. It has been stated that the quantity of briquettes manufactured in Belgium amounts to, approximately, 2,000,000 tons a year, which entails the consumption of 200,000 tons of pitch. In order to obtain this quantity it would be necessary, allowing for an average production of 55 per cent. of pitch from tar, and 3 per cent. of tar, from coal, to carbonise about 10,000,000 tons of coal. Our production of pitch is, therefore, deficient and, in 1925, we produced, only, 124,040 tons of tar, corresponding to about 60,000 tons to 70,000 tons of pitch.

We import, indeed, large quantities of tar, as the following figures indicate :—

	Tons.
1924	30,641
1925	39,746
1926	43,887

and of pitch :—

1924	74,463
1925	121,778
1926	91,114

Among other purposes for which coal is utilised, is that of the production of electricity. The companies, affiliated to the Union of Electric Exploitations, produced 454,000,000 kw., in 1922, 665,000,000 in 1924, and 1,078 millions, in 1926. The quantity of coal employed for this production is nearly 10 per cent. of the entire output of coal, in this country.

These considerations clearly indicate what the economic policy of Belgium as regards fuel should be. It is absolutely necessary to increase the value of the coal. In England, and in Germany, which are the neighbouring countries where the question has received most attention, the problem has been attacked from two points of view. While in Germany efforts are being made to increase the production of oil from coal, in Great Britain, attention has been centred on the production of a smokeless fuel, or in other words, the aim has been to improve the quality of fuel. In Belgium, we must consider these two points of view, at the same time. It is essential that the coal-dust should be utilised, and the only method in use at the present time is the manufacture of briquettes. As has been stated, briquettes are made with the help of pitch, and this necessitates expensive imports. We must endeavour, therefore, to find other binders, less costly, and which could be prepared from native products. On the other hand, processes of low temperature carbonisation, by which we could obtain, from coal-dust, a solid fuel of good quality, should also engage our attention.

The oil problem.

As to the production of oils, Belgium is in the same position as Germany. The whole of the petrol she requires is imported. The import of mineral oils, of density under 0.780 amounted during the last three years to :—

	Metric Tons.
1924	133,314
1925	156,300
1926	110,276

The carbonisation of coal, alone, would make us independent of these imports.

The quantity of coal submitted to high temperature carbonisation, is limited. The quantity of benzol, which the carbonisation of coal, at present used for the making of coke (about 25,000 tons a year) furnishes, would never be sufficient to satisfy the demand.

We must, therefore, consider the possibility of employing processes of low temperature carbonisation, and, also, processes of hydrogenation. It is, at the moment, impossible to say which of these processes will be most utilised in the future. A general statement may however be made : Belgium is not rich in high volatile coal, and a proportion of this coal is used for the manufacture of gas for lighting. In order to free Belgium from the necessity of importing petrol, we must reckon on hydrogenating, about, 1,000,000 tons of coal. But, it is to low temperature carbonisation, that we must turn our attention (the yield of light oils would be increased, if necessary, by submitting to cracking neutral oils from low temperature tar), then, we should have to carbonise even larger quantities of coal.

It is evident from this that Belgium must work on some such lines, and the description of coal produced must be taken into account, to determine the choice of a process of carbonisation.

In bringing this brief resume to a close, I have pleasure in stating that our task will be greatly facilitated, by the abundant research work of high scientific and industrial value which has been accomplished in Great Britain, in the course of the last yew years, in this new domain of the Chemistry of Fuel, which is, already, so rich in future possibilities.

PART I.—PRODUCTION.

Chapter 1.

THE CHARACTERISTICS OF BRITISH COALS.

By L. Slater, Ph.D.

Any attempt to record the types and properties of coal available in Great Britain, must involve some consideration of methods of classification, and, as a classification depends mainly upon data obtained by chemical analysis, there are introduced the correlated questions of methods of sampling and analysis. It is impossible, in the space of this chapter, to consider methods of sampling; for details, reference must be made to technical literature (*a*). It is sufficient to emphasise, that, unless the sample truly represents the bulk of the coal from which it is obtained, analytical data derived therefrom is useless. The properties upon which the utility of a coal depends, may include a characteristic so ill-defined as its hardness, the more definable behaviour, when subjected to carbonisation, and the mode of burning. Means have been sought to express, by the result of empirical tests, some of these properties, the yield of volatile matter and the condition of the carbonised residue giving information, on the one hand, whilst the determination of the calorific value indicates, to some extent, the value of the coal as a combustible. The properties of a coal must depend, in some measure, upon the ultimate composition and hence a knowledge of the percentage amount of carbon, hydrogen, oxygen and nitrogen is required.

As it is not feasible to measure accurately a physical property such as hardness, a classification for general purposes must utilise information more readily accessible, from the determination of volatile matter, calorific value, and the ultimate composition. The determination of volatile matter is an empirical test which must be conducted according to a standard method (*b*). The volatile matter is expressed as the loss in weight that a coal undergoes, when heated at a given temperature for a prescribed period of time, and should be expressed on a basis free from moisture and ash. The determination of the ultimate composition, whilst demanding greater manipulative skill can be carried out with a high degree of accuracy. The amount of nitrogen present in the majority of coals is broadly constant, but the percentage of sulphur, some of which must be considered as adventitous, may vary widely, hence, for the purpose of classification, the amounts of carbon and hydrogen, are expressed on a basis free from moisture, ash and sulphur.

The accumulation of knowledge as to the purposes to which a coal may be most satisfactorily applied, has enabled a grading of coals to be developed based upon their industrial use. Such a grading has become of wide commercial application, and has proved useful as a rough approximation to a form of classification. In this manner it has been applied by H.M. Inspectors of Mines, in recording the types of coals worked in Great Britain. The coals are graded as (1) anthracite, (2) coking, (3) gas, (4) house, (5) manufacturing, (6) steam.

Attempts have been made to correlate the observed behaviour of a coal, in its industrial applications, with the data available from the results of an analytical examination. The first attempt to introduce a more exact definition and classification of coals was made by Regnault and was, later, amplified by Grüner. Regnault showed that the principal types of coals could be defined by their carbon and oxygen content. Grüner extended this work and suggested seven classes based upon the additional observation of volatile matter. The broad divisions of Grüner are: (1) Anthracite; (2) Lean or anthracite coals; (3) Short flame bituminous coals; (4) Bituminous coals; (5) Long-flame bituminous coals; (6) Dry long-flame coals; and (7) Lignites. These divisions have been largely accepted by subsequent workers on the subject.

(a) The Sampling of Coal. F. S. Sinnatt. Lancashire and Cheshire Coal Research Association. Bulletin III.
(b) Methods of Analysis of Coal (1927). Department of Scientific and Industrial Research.

A classification based upon the yield of volatile matter has been suggested by Hilt, and followed by Wedding (*c*) and is as follows:—

Type of Coal.	Percentage yield of volatile per 100 grams of coke.
Lean anthracite coals	5—10
Sintering coals	10—15
Caking coals (old)	15—33
Caking coals (new)	33—40
Sintering coals	40—44
Sound coals	44—50

Such a classification, whilst sometimes suitable in its local application, cannot be used as a general method, since numerous cases have been quoted where coals of similar volatile matter differ greatly in character and composition (*c*). A comprehensive study of methods of classification has been made by Seyler (*d*), who has confirmed the observation of Regnault, that, over a large range, coals of similar character fall between narrow limits of composition, and has shown that an important correlation exists between the volatile matter and the hydrogen content of a coal. Thus for a given carbon content, an increase of hydrogen involves an increase in the volatile matter. It is thus possible to suggest a broad classification, based on a knowledge of the carbon and of the hydrogen content, and to express the relationship in tabular form, as shown, the percentage of carbon being recorded on the horizontal axis and the hydrogen on the vertical axis. A comparatively narrow band, embracing the majority of British coals occupies the area of the squares indicated by heavier type. Those coals which fall outside this band, must be considered to be abnormal in type, such, for example, are the cannel coals. There is recorded upon the table the recognised commercial qualities associated with the types according to this classification. A similar form of classification, with some variations in nomenclature, has been applied to the coals of America, by workers in that country.

Many apparent anomalies occur and records exist of coals with similar composition, differing widely in character and application. But, increasing knowledge of the nature of the coal substance, should enable such amplification and modification to be applied to Seyler's proposed classification, as to render it acceptable alike, to those investigating the more fundamental properties of coals, and those who are concerned with their commercial utilisation.

Some difficulty in applying this classification arises from the lack of accurate analytical data. It has been shown, that the percentages of carbon and hydrogen used must be calculated on a basis free from moisture, ash and sulphur. Such complete data is seldom available, and, when available, the identity of the coal or the origin of the sample is, frequently, in doubt. It is difficult, therefore, in a survey such as forms the subject of this chapter, to adhere strictly to a classification of the type suggested by Seyler. It is proposed to describe the class of coal, by reference to the rough commercial classification, which has been described—that is, as anthracite, coking, gas, house, and steam coal, and, where sufficient analytical data is available, to refer any coal under consideration to its place according to Seyler's classification.

The classification of the coals produced into (1) anthracite, (2) coking, (3) gas, (4) house, (5) manufacturing, (6) steam, agrees with the order suggested by Grüner, except that there are types of semi-anthracites and steam coals, grading into coking coals and occurring between classes 1 and 2.

The anthracites and semi-anthracites.

These are the ortho-anthracite and semi-anthracite coals of Seyler's classification, and, together, occupy the first group. The true anthracites are considered to have a volatile matter content, not exceeding 8 per cent., whilst the carbon will exceed 93 per cent. and the hydrogen fall below 3.7 per cent. These coals burn with a colourless flame and upon carbonisation yield a non-caked residue. The ash content is, in general, low. It is upon these general properties that their main use depends, for they find their application for domestic heating

(c) Grundriss der Eisenhuttenkunde, p. 46. See also Hilt Dingler, 1873/268, p. 424.
(d) Fuel in Science and Practice, 1924, p. 20.

SEYLER'S CLASSIFICATION OF COAL.

Carbon.	Anthracitic.	Carbonaceous.	Bituminous.			Lignitous.	
			Meta-	Ortho-	Para-	Meta-	Ortho-
	Carbon over 93.3 per cent.	93.3—91.2	91.2—89.0	89.0—87.0	87.0—84.0	84—80	80—75
PER-BITUMINOUS GENUS Hydrogen over 5.8 per cent.	—	—	PER-BITUMINOUS (Per-meta-bituminous) *Long flame steam coals*	PER-BITUMINOUS (Per-ortho-bituminous) *Bastard cannels* *Gas coals*	PER-BITUMINOUS (Per-para-bituminous) *Cannels* *Long flame steam coals*	PER-LIGNITOUS	
BITUMINOUS GENUS Hydrogen 5.0—5.8 per cent.	—	(Pseudo-bituminous species)	**Meta-bituminous** *Welsh coking coal*	**Ortho-bituminous** *Durham coking coals* *Smithy and gas coals*	**Para-bituminous** *Long flame steam coals* *Coking coals* *Best gas coal*	**Lignitous** (Meta-)	(Ortho-)
SEMI-BITUMINOUS GENUS Hydrogen 4.5—5.8 per cent.	—	**Semi-bituminous** SPECIES (Ortho-semi-bituminous) *Steam Coals (coking)* *Higher Index blended for coke*	SUB-BITUMINOUS (Sub-meta-bituminous) *House coals* *Continental coking when Index high*	SUB-BITUMINOUS (Sub-ortho-bituminous) *Coking and steam*	SUB-BITUMINOUS (Sub-para-bituminous)	SUB-LIGNITOUS (Meta-)	(Ortho-)
CARBONACEOUS GENUS Hydrogen 4.0—4.5 per cent.	Semi-anthracitic species *Dry (non-caking) steam*	**Carbonaceous** SPECIES (Ortho-carbonaceous) *Welsh smokeless steam (slight caking)*	Pseudo-carbonaceous (Sub-meta-bituminous) *Steam coals*	Pseudo-carbonaceous (Sub-ortho-bituminous)	Pseudo-carbonaceous (Sub-para-bituminous)		
ANTHRACITIC GENUS Hydrogen under 4 per cent.	**Ortho-anthracite** *True anthracite*	Pseudo-anthracite (Sub-carbonaceous)	Pseudo-anthracite (Sub-meta-bituminous)	Pseudo-anthracite (Sub-ortho-bituminous)	Pseudo-anthracite (Sub-para-bituminous)		

N.B.—The various genera are arranged in column I. vertically according to the hydrogen. The species in each genus are arranged horizontally according to the carbon.

(From Analysis of British Coals and Cokes, 1924)

in enclosed stoves, in gas producers, as an ingredient of briquettes and for malt and hop drying. With an increase in hydrogen to 4 per cent., the volatile matter increases to 10 per cent. and the coals pass into the semi-anthracites.

Steam coals.

These coals cover a range which, excluding those coals used exclusively for coking purposes, embraces the South Wales steam coals (the carbonaceous and semi-bituminous coals of Seyler's classification), and the steam coals of Durham, Scotland and the Yorkshire-Notts area (classified by Seyler among the para-bituminous and lignitous coals). The South Wales steam coals have a carbon content of 93-91 per cent. and hydrogen 4.0 to 5.8 per cent., the lower hydrogen range including the best types of Admiralty steam coals, whilst, the higher hydrogen range, includes the more common type of steam coals, which may require blending for satisfactory use. The higher carbon steam coals of Durham and Northumberland, have a carbon content of 87 per cent., or less, and are classed as para-bituminous, those of Derbyshire and Notts with a carbon content of 82 per cent. are called lignitous. That a range of coals so wide, can fulfil the requirements of a steam coal, is an indication of the variety of methods of firing and the widely varying conditions imposed, during the process of steam-raising.

There are, however, certain qualities which a steam coal must possess to be of use for this purpose. They should be free burning, that is, they should not cake, and, by forming a coke on the fire bars, impede the draught. The calorific value should be high and the moisture, ash and sulphur low. The melting point of the ash is an important consideration, and should be sufficiently high to prevent excessive clinkering, under the conditions of firing. A melting point exceeding 1,350° C. is desirable. Coals which serve for use as locomotive fuels and for bunkering purposes, must possess additional properties. They should withstand the effect of transport and frequent handling, weather well, and be capable of storage in large bulk, without risk of spontaneous firing.

Coking coals.

In a consideration of their properties, it is essential to define what is inferred by the phrase " coking coals." A coking coal is one which, when carbonised in the form of small slack, will produce a saleable metallurgical coke. The variety of coals used for coking purposes is almost as wide as that for steam purposes, and ranges from the high carbon coals of the South Wales area (the meta-bituminous class with a carbon content of 90 per cent. and a volatile matter content of 20 per cent.), to the coking coals of the Midlands, with a carbon content of 84-82 per cent. and a volatile matter content up to 37 per cent. (the meta-lignitous class of Seyler's classification). It is difficult to define that property of the coal substance which confers upon a coal its ability to produce a coke, for the nature of the coking process is very imperfectly understood. It may be stated that coals which, in such a test as the standard test for the determination of volatile matter, produce a caked and swollen carbonised residue will, in general, form satisfactory coking coals, either alone or when blended with other coals. The presence of an excessive amount of certain impurities may, however, restrict the use of a coal, when its coking properties may, otherwise, be deemed satisfactory. Such, for example, are sulphur and phosphorus, which are undesirable when certain qualities of metallurgical coke are required, or arsenic, when the coke is to be used for malting purposes. In coking coals, a low ash content is essential. The best quality coking coals are derived from the Durham area, and, to a smaller extent, from South Wales, from the range of coals classified by Seyler as ortho-bituminous. They have a composition of, approximately, carbon 88 per cent. and hydrogen 5.5 per cent., and a volatile matter content, less than 30 per cent. Their moisture content is low and seldom exceeds 2 per cent. There are, however, in other areas, a number of coals from which satisfactory cokes are produced, and with improved methods of coking, good cokes may in the future be produced from a further large class of coals, which are not devoid of coking properties, but, at present, find their main outlet as gas and household coals.

Gas coals.

Whilst the essential product from a coking coal is the coke, from a gas coal, it is the gas; hence, in general, a gas coal, whilst of similar properties to the former class, will have a higher volatile matter content and the coking power will tend to be inferior by comparison. The range of gas coals will thus exclude the more highly coking of the ortho-bituminous class, and include some of the better coking members of the meta-lignitous class. The

majority of the gas coals occur in the para-bituminous class, with a carbon content ranging from 87-84 per cent., and hydrogen 5-5.8 per cent., and a volatile matter content of 30-40 per cent.

House coals.

The types of coal constituting the class known as house coals, occupy, with the exception of the very strongly coking coals, the whole range of the bituminous class. It is difficult to describe the properties of such a type of coal, for it depends largely upon the local supply and, to some extent, upon local usage. For the supply of the best quality house coals in some areas, a bright coal is in demand, in others, a dull coal is accepted; in the north of England, a coal giving a red or brown ash is required, but, in other parts of the country, a coal with a white ash is accepted. A coal for house purposes should be reasonably pure and free from adventitious dirt and interbanded fragments of shale and pyrites, and be of medium hardness. As free burning qualities are desirable, the coal should be only slightly coking.

Manufacturing coals.

It is difficult to distinguish between coals to be applied to manufacturing, and those for household purposes, for it is a common practice to reserve the smaller sizes from the house coal seams, to size and frequently wash, and to apply them to general manufacturing processes. A coal which cokes strongly is undesirable. Important uses of manufacturing coals are in kilns, and, in the metallurgical industry, for firing reverberatory furnaces, where long flaming coals are required which readily lose their volatile contents. For producer-gas manufacture, a coal of moderately low volatile matter content (30-33 per cent.), and of feeble or non-coking properties is desirable. The sulphur should be low, and the melting point of the ash high.

In the following survey of the coals available in Great Britain, the coal-bearing areas have been considered, according to the districts recognised for inspection purposes by H.M. Inspectors of Mines, and to their geological occurrence, and may be divided into a Northern, a Midland, and a Southern area. The Northern area comprises the coalfields of Scotland, Durham and Northumberland, and Cumberland. The Midland area, the coalfields of Yorkshire, Derbyshire and Nottinghamshire, the Lancashire and Cheshire area, the coalfields of North Wales, of Staffordshire, Warwickshire and Leicestershire. The Southern area includes the coalfields of South Wales, Forest of Dean, Somerset, Gloucester and Kent.

NORTHUMBERLAND AND DURHAM COALFIELD.

The coals of this area cover the whole range of steam to coking coals and, whilst all intermediate types are produced, it must be considered as the chief coking coal area of Great Britain.

In a total of 50,349,937 tons of coal produced in 1924, 6,853,270 tons were converted into coke. The coking coal area occupies a broad belt in Durham, extending from Mickley and Blaydon, in the north, in a south-easterly direction to Bishop Auckland and Ferryhill, in the south. Gas coals of various grades are produced, generally, over the whole area, but the main gas-coal region extends east and west for some distance from Chester-le-Street. House and steam coals are also produced generally, but the main areas are the eastern Tyne-Wear and the Hetton-Haswell districts. North of the Tyne, whilst some gas coals are produced, the majority of the coals are free-burning and make satisfactory steam and house coals.

In this coalfield, the correlation of the seams worked over a wide area is uncertain, for the same seam is known by different names, and the same name is applied to seams on widely different horizons. Wide variations in quality may also occur, as the seams are traced from district to district, steam coals giving place to gas coals, and to steam coals again.

In the carboniferous limestone series, the seams of any importance are the Shillbottle and the Little Limestone, worked in the Haltwistle district, and in the Valley of the Tyne.

An analysis of the Little Limestone coal given by Gibson (f) shows: Carbon, 76.81; hydrogen, 5.30; oxygen, 7.44; nitrogen, 1.63; sulphur, 2.02; ash, 4.70; volatile matter, 35.5.

(f) Coal in Great Britain. Walcot Gibson, 1920, p. 253.

The main seams in the chief productive coal measures, given in ascending sequence are: Brockwell; Three Quarter or Yard of Wylam; Lower Five Quarter; Six Quarter or Busty; Stone; Tilley; Harvey; Townley or Beaumont; Hutton of Wear or Low Main of Tyne; Maudlin or Bensham; Yard of Northumberland; Metal; Stone or Five Quarter; High Main. Of these, where they are workable, the Brockwell, Yard, Busty and Harvey form the chief coking coals, the Hutton and Maudlin and, to some extent, the Five Quarter and Townley produce excellent gas coals. The Brockwell seam occurs over a wide area and is stated by Gibson (g) to have a composition of : Carbon, 81.93 per cent.; hydrogen, 4.85; oxygen, 6.47; nitrogen, 0.69; sulphur, 0.65; ash, 3.86; and water, 1.55 per cent. Mott (h) gives: Carbon, 86.8; hydrogen, 4.9; oxygen, 6.5 (on ash-free, dry basis); and volatile matter, 28.7 per cent. This coal forms an excellent coke, and falls in the ortho-bituminous class of Seyler's Classification.

The Busty seam, especially in the Chopwell, Consett and Willington areas, is reported to be an excellent coking coal. An analysis by Mott (i) gives: Carbon, 88.8; hydrogen, 5.0; oxygen, 3.9 (on ash-free, dry basis); volatile matter, 25.0 per cent.

The Lower Five Quarter, worked over a large area in the West and South-west of Durham, also provides a good coking coal. The Beaumont seam known as the Townley, forms a good gas coal and, whilst inferior in coking qualities to the seams below, forms a constituent of many coking slacks. The composition is stated by Gibson (j) to be: Carbon, 84.50; hydrogen, 5.15; nitrogen, 1.43; oxygen, 6.93; sulphur, 0.63; ash, 1.36 per cent.; the seam would, therefore, occur in the para-bituminous class of Seyler's Classification.

The Hutton of the Wear and Low Main of the Tyne is probably the most important seam in the coalfield, producing an excellent gas, house and steam coal. It is of variable quality, the volatile matter content having been shown by Briggs (k) to be at a minimum of 25 per cent. in the Durham area, increasing to a maximum of 40 per cent., when traced radially from this centre. North of the Tyne, in the Seaton Delaval-Cramlington area, the seam produces a good steam coal, south of this area, between the Tyne and Wear, it forms a good gas coal, whilst in the Hutton-Haswell area, it is a good quality house coal. The composition of the Low Main is stated by Mott (l) to be: Carbon, 85.5; hydrogen, 5.4; oxygen, 6.4 (on ash-free, dry basis), and volatile matter, 34.0 per cent. ; and by Seyler (m) two samples giving: Carbon, 89.73; hydrogen, 6.03; and oxygen, 5.72 per cent. An analysis of the Hutton seam in Durham area is stated to be (n): Carbon, 80.51; hydrogen, 4.80; oxygen, 6.82; nitrogen, 1.44; sulphur, 2.07; ash, 3.00; and moisture, 1.36 per cent. These results indicate a wide variation in composition and properties, the coals quoted by Seyler occurring in the meta-bituminous class, the others, in the para-bituminous class. The Bensham seam, which is also known as the Maudlin in Durham, is worked mainly as a gas coal, but in the South East area of the field it produces a steam coal. In some areas, whilst not coked alone, it forms a constituent of coking slacks. The composition of the Maudlin seam is stated by Mott (o) to be: Carbon, 84.3; hydrogen, 4.8; oxygen, 8.0 (on ash-free, dry basis); and volatile matter, 30.5 per cent.

The Yard seam of Northumberland, the Five-Quarter and the High Main, are of importance in the north of the field, where they form the major part of the steam and house coal production.

CUMBERLAND COALFIELD.

The coals in this area are classed as available for all commercial purposes, but the area essentially produces coking coals. In 1924, 2,190,480 tons were raised and 716,631 tons used for coke making. The majority of the coals raised, are coking coals of various grades, their use being determined, not so much by their coking qualities, as by their freedom from impurities, of which phosphorus would appear to be the most important. In the Whitehaven area, the chief seams are the Main Band, Bannock Band, Six Quarter, Yard Band, and Little Main, of which, the Main Band and Bannock Band form the chief coking coals. An analysis of these is stated by Mott (p) to be:—

	Carbon.	Hydrogen.	Oxygen.	Vol. Matter.	Moisture.
Main Band	84.8	5.4	6.3	33.0	2.58
Little Main	84.5	5.7	7.0	33.3	0.80

(g) Op. cit. p. 259.
(h) Mott. Fuel in Science and Practice, 1925, p. 468.
(i) loc. cit.
(j) Op. cit.
(k) Briggs Trans. Inst. Min. Eng. Vol. LXV., p. 191.
(l) loc. cit. p. 468.
(m) loc. cit. p. 44.
(n) Analyses of British Coals and Cokes, 1924, p. 139.
(o) loc. cit., p. 468.
(p) loc. cit., p. 468.

They would occur in the para-bituminous class of Seyler's Classification. In the Harrington district, the Six Quarter, Little Main and Four Foot are worked. To the North East of the field, a number of seams are worked, including the Ten Quarter, Little Main, Metal, Yard, of which, the Ten Quarter is stated to represent the Bannock Band, and the Metal Band, the Main Band. The Lickbank seam is of importance, locally, in the Workington area.

The seams find a general application for coking, gas and household purposes.

LANCASHIRE AND CHESHIRE COALFIELD.

The distribution of coal in this area, may be most conveniently considered, by recognising that the field is divided into the Burnley area, where the Lower coal-measure seams are of importance, and the South Lancashire coalfield, in which, the chief seams occupy the Middle coal measures. To the south-east, this field extends into Cheshire as far South as Macclesfield. In general, whilst some of the coal is used for the production of coke, the greater part of the output of the coalfield finds its main application for gas, household, steam and general manufacturing purposes. In 1924, the coal produced was 19,790,078 tons, of which, 741,922 tons were used for coking purposes.

In the northern area, which is known as the Burnley field, the principal seams beneath the Arley mine are, in descending order, the Upper Mountain Mine, Upper Foot and Lower Mountain, the two latter seams continuing south of Burnley to form the Mountain Mine. This is a coking coal and produces a good quality foundry coke of low sulphur content. Its analysis is stated by Mott (q) to be: Carbon, 86.1; hydrogen, 5.3; oxygen, 6.1; and volatile matter, 20.7 per cent. The Arley and Dandy coals, lie above the Upper Mountain Mine and are worked for gas and household purposes. The South Lancashire field, in which the Middle coal measures are the more productive series, has, as a base, the seam known generally as the Arley. This part of the field is broken by numerous faults and the resulting uncertainty of correlation, renders any systematic survey of the field difficult. Above the Arley, in sequence are the Orrel Five Feet, Yard, Smith, Ravine or Plodder, and Trencherbone. Between these latter seams, certain small seams, such as the King, Queen and Cannel, occur irregularly and are of local importance.

The Trencherbone, or its equivalent the Wigan Nine Foot is succeeded by the Wigan and Pemberton groups of seams, of which the Wigan Four Feet and Five Feet and the Pemberton Four Feet and Five Feet are of importance. This sequence is followed by the Rams, Brassey, Crombouke and Binn. Their equivalents in the St. Helens area, appear to be Earthy and Potato Delf and the Lower and Higher Florida.

The Arley Coal and its equivalent, the Little Delf, is especially valuable as a gas coal. Blended with other seams, it is used, to some extent, for coking purposes and is largely used as first-quality house coal, and for steam raising. A typical analysis shows the composition to be:—Carbon, 85.12; hydrogen, 5.70; oxygen, 6.09; nitrogen, 1.59; sulphur, 1.50, and volatile matter, 35.81 per cent.; with a calorific value of 14,700 B.Th.U. This composition varies but little over a wide area (r) and suggests, that it belongs to the para-bituminous class of Seyler's classification.

Above this seam, occurs the Smith seam which, owing to the gradual exhaustion of the Arley, is, in conjunction with a neighbouring Yard seam, becoming more widely worked. The Smith seam, is a gas and household fuel and also forms a constituent of coking slacks. A typical analysis is: Carbon, 83.25; hydrogen, 5.31; nitrogen, 1.66; sulphur, 1.66; oxygen, 8.12; volatile matter, 38.4 per cent.; and calorific value, 14,500. The ash and sulphur contents are variable, restricting the use for gas purposes (s).

The Ravine seam, reaches its best development in the Bickershaw district and, where worked, produces a satisfactory gas and household coal. An analysis of the seam in this area gave: Carbon, 83.36; hydrogen, 5.26; nitrogen, 1.58; sulphur, 3.50; oxygen, 6.30; calorific value, 13,530; volatile matter, 34.68 per cent. (t). The King Mine is of importance locally, and produces a gas and household coal, and also forms a constituent of some coking slacks.

(q) Loc. cit. p. 468.
(r) Department of Scientific and Industrial Research. Fuel Research Division, Physical and Chemical Survey of the National Coal Resources, Bulletin No. 3.
(s) Physical and Chemical Survey of the National Coal Resources. Bulletin No. 5.
(t) Physical and Chemical Survey of the National Coal Resources. Bulletin No. 4.

The Trencherbone, now largely exhausted, forms a gas and household coal, and also produces a satisfactory steam coal. The Wigan Four Feet in many areas, forms a good gas coal and is utilised for coking purposes. The remaining seams, whilst used to some extent for gas, are mainly wrought for household, steam and general manufacturing use.

In the extension of the coalfield into Cheshire, the seams worked are the Roger, Great and Town Lane, which are used for gas-making, but, mostly, for household and general manufacturing purposes.

YORKSHIRE, DERBYSHIRE AND NOTTINGHAMSHIRE COALFIELD.

This area, more frequently known as the East Midland coalfield, may be conveniently considered as a whole, for seams occur in it which can be traced throughout. The area forms an elongated basin, the coals forming an outcrop on the eastern edge, a covering of newer rocks concealing the extent of the productive measures to the east.

The distribution of the coal in this area, is best considered with reference to two seams which, with their equivalents, are persistent throughout. These are the Silkstone or Black Shale seam, which forms the base of the Middle coal measures, and the Barnsley or Top Hard seam. To the north of Barnsley, these seams deteriorate rapidly, whilst to the south, they become gradually non-coking, until in the Derbyshire area the Top Hard seam is a steam coal. The Black Shale retains its coking power as far south as Alfreton. A similar vertical graduation is observable, in that the seams above the Barnsley, are in general non-coking, whilst below, their coking value increases with depth.

In the year 1924, this coalfield produced 76,361,968 tons, of which 6,275,710 were converted into coke.

The coals of the Lower coal-measures are, mainly, of importance in the north and north-west, and towards the south-west of the field, and in these areas reach importance, locally. Of the coals in this series, the Ganister, Alton or Halifax Hard bed, can be traced over the whole field, and has been correlated with the Upper Mountain Mine of Lancashire. It is of importance, because of the associated bed of ganister, a high grade refractory material.

In the Bradford-Wakefield area, the Halifax Soft below, and the Better Bed above, are of good coking quality and low in sulphur. They are used for the production of special metallurgical cokes, of low sulphur content. The following analyses are given by Gibson (u):—

	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Sulphur.	Ash.	Water.
Better Bed	83.45	5.38	7.63	0.41	1.08	2.08
Halifax Soft	84.03	4.08	7.11	0.41	1.75	1.72

The volatile matter content is usually about 30.0 per cent. They are classified as ortho-bituminous, and compare favourably with the better coking Durham coals.

Above these seams, occurs the Kilburn, which is of importance, locally, in Derbyshire as a house coal. The most important coals of this Lower Coal Measures series, are the Whinmoor, which is worked in the Barnsley area, and its equivalent, the Beeston seam of the Leeds-Castleford area. Both seams produce a satisfactory gas and house coal. The Silkstone seam, which forms the base of the Middle coal-measure series, is of considerable importance in the Barnsley-Sheffield area, and as the Black shale in Derbyshire. In the former, it produces an excellent coking coal, in many areas forming a large proportion of the coking slacks, and is used for gas and household purposes. To the south, whilst still coking, it has greater value as a gas coal.

South of Alfreton, the coking value is inferior. An analysis of a sample of South Yorkshire Silkstone is given by Mott (v): Carbon, 85.6; hydrogen, 5.5; oxygen, 7.0; with volatile matter of 33.9 per cent.; whilst the Black Shale has: Carbon, 82.6; hydrogen, 5.2; oxygen, 7.7; and a volatile matter, 33.5 per cent. Each would fall in the para-bituminous class.

Above the Silkstone, is the Middleton Main, a seam frequently worked in West Yorkshire as a gas and household coal. In the Derbyshire and Nottinghamshire areas, the Tupton or Low Main is largely worked as

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(u) Op. cit. p. 177.
(v) Loc. cit.

a gas and house coal, and, in the Derbyshire area, forms a large proportion of the coking slacks used. An analysis given by Gibson (w) is as follows: Carbon, 67.93; hydrogen, 4.45; oxygen, 10.16; nitrogen, 1.22; sulphur, 0.62; ash, 3.84; and moisture, 11.58 per cent.; which places the coal in the meta-lignitous class. The Thorncliffe, a gas coal, occurs, approximately, in the same horizon as the Tupton, and is worked widely, north and south of Sheffield. It is of moderate coking power, but frequently forms part of the coking slacks.

The Parkgate of South Yorkshire and its equivalent, the Deep Hard of Derbyshire and Nottinghamshire, is a valuable seam over a large area. In the north, it produces a coking, gas-making, and household fuel, whilst the middle portion of the seam, known as the " Hards," produces a steam and locomotive fuel. When traced into the South of the field, its coking power decreases, and it is utilised for steam and household purposes. An analysis of Parkgate brights and Hards is given by Mott (x) as:—

	Carbon.	Hydrogen.	Oxygen.	Volatile Matter.
Parkgate Brights	85.4	5.6	7.3	36.4
Parkgate Hards	83.3	5.1	9.9	33.5

The Brights would, thus, fall in the para-bituminous class. In Derbyshire, the volatile matter and moisture have both increased, an analysis (y) at Hardwick showing: Carbon, 75.00; hydrogen, 4.77; oxygen, 8.24; nitrogen, 1.26; volatile matter, 39.00; and moisture, 5.20 per cent.

Above the Parkgate, occurs the Flockton, widely worked in Yorkshire; in Derbyshire, the corresponding seam, the Deep Soft, is of importance, furnishing a gas and household coal, and a constituent of coking slacks. The Parkgate, is succeeded by the Swallowood, which, to the north-east of Sheffield, produces a steam and house coal. To the south-east of Leeds, this seam is represented by the Haigh Moor, and after the Beeston, is, perhaps, of greatest importance in this area, being worked as a house and gas coal.

The Barnsley or Top Hard seam, is the most important seam of the coalfield, occurring in a workable thickness from south of Wakefield to Nottingham. In the concealed coalfield, it has been proved at Thorne, in the north, and at Doddington, in the south. The best development is in the South Yorkshire area, where 9ft. of coal occurs, consisting of bright coal forming a gas, house and coking coal, and a hard, dull coal, producing the South Yorkshire Hard steam coal. To the south, the bright coal is reduced in amount, and the hard coal predominates, the seam being known as the Top Hard seam. In general, the seam is of exceptional purity, and is of low sulphur content. There is a gradual reduction in the carbon content, and an increase in the oxygen, as the seam is traced to the south. At Elsecar, South Yorkshire, and near Watnall, Notts, the composition of the " Hards " is stated to be (1):

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Moisture.	Ash.	Sulphur.	Vol. Matter.
Elsecar	80.17	4.92	6.95	2.15	2.01	3.10	0.51	33.29
Watnall	75.09	4.51	12.13	1.21	8.37	6.37	0.69	39.90

The " Hards " from the seam stands transport well, and deteriorates slowly on storage. The ash content is generally low and calorific value high, hence, this portion of the seam is much in demand as a locomotive fuel and for bunkering purposes. Furthermore, the low sulphur content, the high melting point of the ash, and the freedom from caking, render it an excellent producer coal, and for use in certain metallurgical processes.

Above the Barnsley, the seams are less coking in quality, and are of importance, only, locally. The High Hazels, a house coal and the Kents Thick are mined, whilst, in the Barnsley area, the Beamshaw and Melton fields seams, are used, to some extent, for gas purposes and, in conjunction with other seams, for coking. The Shafton is also worked, locally, as a house coal.

NORTH WALES COALFIELD.

The North Wales coalfield, which extends into Flintshire and Denbighshire, produced in 1924, 3,445,673 tons of coal. This area, is divided by the Bala fault into two smaller fields, the coals occurring in the one, the

(w) Op. cit.
(x) Loc. cit.
(y) Analyses of British Coals and Cokes, 1924, p. 165.
(1) Analyses of British Coals and Cokes, 1924, p. 153.

Flintshire field, being mostly house and steam, and in the other, the Denbighshire field, gas, house and steam coals.

The Main seam is recognised over the entire coalfield, and is worked for gas and steam purposes. Its analysis at Plas Power (2) is given as: Carbon, 77.77; hydrogen, 5.15; oxygen, 8.65; nitrogen, 1.54; volatile matter, 36.20; moisture, 3.10; ash, 2.45; and sulphur, 1.34 per cent., and falls in the meta-lignitous class.

In the Denbighshire area, the most important seams worked are in ascending order, Wall and Bench, Lower Yard, Red, Main, Brassey, Crank, Two Yard, Powell and Drowsall. A small amount of coke is made in the Brymbo-Moss area. In the Flintshire area, the chief seams are the Queen, Premier, One, Two and Three Yard, Main, and Hollin. These seams are stated to produce house, manufacturing or steam coals.

NORTH STAFFORDSHIRE COALFIELD.

In 1924, this coalfield produced 6,495,353 tons of coal, of which, approximately, 1,000,000 tons were converted into coke. The coals are used for all commercial purposes, but the coking and gas coals, are confined to the western part of the field, the north and eastern area providing, mainly, non-coking and free burning types. In ascending order, the seams worked are the Crabtree or Four Feet, to a limited extent in the western part of the field, Bullhurst, Cockshead or Bambury Eight Feet, Bambury Seven Foot, Hard Mine, Holly Lane, Bowling Alley, Ten Feet, Yard and Moss coal. Of the upper series, which are mainly non-coking, the coals used for house or steam purposes and for pottery firing, are the Cannel, Great Row, Peacock, and Ash coals.

The coals in the eastern part of the field, are, mainly, applied to manufacturing purposes and for household use. The Hard Mine provides a satisfactory locomotive fuel. In the western area, the coals develop sufficient coking quality, to permit of their use as gas and coking coals. The seams most used for this purpose, are the Ten Foot, Seven Foot Bambury, the Cockshead and Bullhurst. In the north of the field, the Seven and Eight Foot Bambury seams lose their coking qualities. The analysis of a coking coal is (3) : Carbon, 76.97; hydrogen, 4.84; nitrogen, 1.47; sulphur, 1.57; oxygen, 7.55 ; volatile matter, 33.81; moisture, 2.65; and ash, 4.95 per cent. This coal is of the para-bituminous class. An analysis of the Ash coal is stated to be : (4) Carbon, 70.04; hydrogen, 5.04; oxygen, 12.02; nitrogen, 1.32; volatile matter, 33.40 ; moisture, 3.60; ash, 5.98 ; sulphur, 0.82 per cent. and is in the meta-lignitous class.

LEICESTERSHIRE COALFIELD.

This coalfield, with Ashby-de-la-Zouche at its centre, comprises part of the counties of South Derbyshire and Leicestershire. The output in 1924, totalled 4,396,406 tons. The coals produced are, essentially, non-coking, and have a, relatively, high moisture content. They are applied, chiefly, for domestic use and for manufacturing purposes. In the western part of the field, which falls mainly in South Derbyshire, the chief seams worked are in ascending order, Kilburn, Stanhope, Eureka, Stockings, Woodfield, Main, Five Feet and Ell. The Main coal is the chief seam. In the west of the field, the important seams are the Upper, Middle and Lower Lount and the Main. The coals are of the ortho-lignitous class. Analyses of the Main seam, at Nailstone and at Ellistown, are:—

	Carbon	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Vol. Mat.	Moisture.	Ash.
Nailstone (5)	63.97	4.23	11.30	1.02	1.21	46.4	14.08	4.2
Ellistown (6)	74.50	5.65	15.60	1.50	2.75	39.72	—	—

WARWICKSHIRE COALFIELD.

The coal is worked over a narrow belt, extending from Tamworth in the north, to the south of Coventry. The output in 1924, amounted to 5,147,000 tons classed as house, steam and manufacturing coal. In the north of the field, many seams are worked, of which the Seven Feet, the Bench and Deep are persistent. In

(2) Analyses of British Coals and Cokes, 1924, p. 179.
(3) Private communication to writer.
(4) Analyses of British Coals and Cokes, 1924, p. 183.
(5) Analyses of British Coals and Cokes, 1924, p. 171.
(6) Fuel Research Board Technical Paper, No. 16. The Primary Decomposition of Coal, Part I. J. G. King & R. E. Willgress.

the south, a number of seams unite to form the Thick seam, which is also known as the Hawkesbury. This composite seam is made up of the Two Yard, Bare, Ryder, Ell and Slate coals, and is generally worked to the south of the field. The coals are similar in type to those occurring in Leicestershire.

SOUTH STAFFORD COALFIELD.

This extends from Rugeley, in the North, to Stourbridge, in the South. The output, in 1924, was returned at 8,793,092 tons. The coals are mainly used for house, steam and manufacturing purposes, and, in the north of the field, are obtained from the following seams which, in ascending order, are Deep, Shallow, Cinder, Bass, Yard, Eight Foot, Five Foot, Four Foot and Broach. To the south of the field, a number of these come together, to form the Ten Yard or Thick seam. In this area, also, are worked the Broach and Heathen. The coals are of the ortho-lignitous class, and are largely used for the varied metallurgical industries of this area. Analyses of these coals is stated by Percy (7) as:—Carbon, 76.12; hydrogen, 4.83; oxygen plus nitrogen, 16.72; sulphur, 1.00; and ash, 2.33 per cent. The moisture of the Thick seam, varies from 10 to 14 per cent. and the volatile matter, from 36 to 38 per cent.

SHROPSHIRE COALFIELD.

This is a small coal-producing area, the output, in the year 1924, being 819,515 tons. The product is, mainly, house and manufacturing coal with some outlet for smelting purposes.

The Southern area, comprises the coalfields of South Wales, the Forest of Dean, Bristol, Somersetshire and East Kent.

SOUTH WALES COALFIELD.

It is difficult to describe the distribution and types of coals in South Wales, without some reference to the geology of the coalfield. The field takes the form of an elongated basin, which contracts to the west, into a narrow strip. It is surrounded on all sides by the older rocks, hence, outcrops are the feature of the limits of the field, and the deepest seams occur towards the centre. The essential feature of the coalfield, is the presence of large deposits of anthracite and a regular gradation of the coals from anthracite to bituminous coking, and house coals. The range and distribution of these types, has been studied by Strahan and Pollard, and published in the Memoirs of the Geological Survey, 1915. There has been shown to be variation in the degree of anthracitisation with depth, and in general, the lower the seam, the higher the carbon content. There is a similar variation horizontally, anthracites in the west, becoming more bituminous when traced to the east, and in similar manner, from the north to the south. The north to south change is more rapid than the west to east, thus, the general change from anthracite to bituminous coals has a south-easterly trend. The coals along the southern and easterly outcrops, are, thus, highly bituminous and, as these coals dip into the basin of the field, they become less bituminous, the upper coals still maintaining their bituminous character. This gradual change continues until the coals, when traced into Carmarthen and Pembrokeshire, have become anthracites. The change is shown by the following analysis of the Mynyddislwyn seam, and its equivalents when traced from Carmarthen into East Glamorgan (from the Memoirs of the Geological Survey, 1915).

	Stanllyd (Anthracite).	4 Feet (Steam).	No. 3 Rhondda (Manufacturing).	Mynyddislwyn. (House).
Carbon	94.43	92.00	88.44	87.66
Hydrogen	3.33	4.34	5.32	6.09
Oxygen	1.27	2.44	5.11	4.38
Nitrogen	0.97	1.22	1.13	1.87

The output of coal from the South Wales area, in 1924, totalled 50,085,135 tons, of which 4,971,423 tons were classed as anthracite, while 2,106,267 tons were converted into coke. There is much confusion in the nomenclature of the seams mined in various districts, which renders a systematic survey of the

(7) Percy's Metallurgy, Fuel, etc., 1875, p. 325.

characteristics of the coal difficult. Over a wide area, embracing Kidwelly, Llanelly and Glen Neath, the coals are anthracites. The chief seams worked are the Big Vein, Stanlydd, Brass Vein, and Diamond Vein. An analysis of the Brass Vein is given by Seyler (8): Carbon, 93.50; hydrogen, 3.54; oxygen and nitrogen, 2.96; and volatile matter, 7.25 per cent. These coals find a wide application for export purposes, for domestic use, in producers, for malt and hop drying, and as a constituent in the briquettes of the patent fuel industry. From the area between the Taff and the Neath Valleys, the dry steam and smokeless steam coals are produced from the Lower steam coal series, the chief seams being the Two-foot-nine, Four Foot, Yard, Red, Nine Foot and Seven Foot. An analysis of the Four Foot, from the Aberdare district, is given by Seyler (9) as: Carbon, 93.30; hydrogen, 4.39; oxygen and nitrogen, 2.31; and volatile matter, 15.00 per cent. From this range of coals is derived the Admiralty steam coals, and the best quality of steam coals for export. Surrounding this smokeless steam coal area, is a more bituminous series of coals, represented by the Three Foot, Five Foot and Six Foot of the Swansea area, and the Five Foot and the Upper Four Feet in the Ebbw Valley, and the Four Feet in the Pontypridd area.

Coking, gas and manufacturing coals are derived from an area which runs parallel to the outcrop, broadening as it enters Monmouthshire, between Pontypool and Bargoed. Coals used for coking and gas making purposes to the west of Swansea are, the Penclawdd and Four Feet, in the Port Talbot area, Rock Fawr, in the Meiros-Llantrisant area, Rhondda 1, 2 and 3, whilst to the east and north east are Big Vein, Rock Vein, Black Vein and Mynyddislwyn.

The following analyses are given by Seyler (10):—

	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Volatile Matter.
Rhondda No. 3...	89.98	5.53	4.50	27.6
Rock Vein ...	87.63	6.14	6.23	38.2
Rock Fawr ...	84.78	5.57	9.65	44.3
Black Vein ...	86.19	5.41	8.40	31.70

FOREST OF DEAN.

The coal raised in this area is, mainly, house and steam in type, a small proportion being raised for gas-making purposes. The Coleford High Delf is the main seam, supplying coal for all purposes; other seams worked are the Rockey, Starkey, Brazilley and Churchway High Delf. In the year 1924, the output of coal was 1,348,612 tons. The coals of the Somersetshire and Gloucestershire coalfield, the output of which, in 1924, amounted to 1,374,718 tons, are coking, gas and house in type. In the northern part of the field, in the Bristol area, the chief seams worked are the Two Feet, Kingswood, Great, Five Coal, Hard Seam, Red Ash, Hard Vein. The lower seams are coking and gas coals. In the southern part of the field, the main seams are the Great, Top, Little, Middle, Bottom and Slyving. Analyses of the Great Vien at Dunkerton, and the Kingswood Great Vein are (11):—

	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.	Volatile Matter.	Moisture.	Ash.
Great Vein ...	81.64	5.29	1.46	5.12	0.67	39.4	1.72	4.10
Kingswood Great	81.82	4.63	1.39	5.54	0.92	—	1.60	4.10

KENT COALFIELD.

This coalfield has been only partially developed, and the value of the seams available, and their correlation are only imperfectly known. Coking, gas and steam coals of, comparatively, low volatile matter content are produced, analyses (12) shewing variation from 20.87 to 28.76 per cent. An analysis of the Five Foot seam, at Tilmanstone, is given by Gibson (13) as: Carbon, 79.12; hydrogen, 4.66; oxygen, 5.90; nitrogen, 1.13; sulphur, 2.30; ash, 5.87; and moisture, 1.02 per cent.

(8) Seyler Loc. cit., p. 41.
(10) Seyler Loc. cit., pp. 44-47.
(11) Gibson Op. cit., p. 138.
(12) Analyses of British Coal and Cokes, 1924, p. 215.
(13) Op. cit., p. 149.

NORTHERN AREA—SCOTTISH COALFIELDS.

The coals of Scotland are distributed in a series of basins, which extend from the Firth of Clyde to the Firth of Forth, the northern extension being defined by a line from Greenock to Stonehaven, and the southern limit, from Girvan to Dunbar. The central area is occupied by the Lanarkshire coalfield, with a small isolated area, the Douglas coalfield to the south and the Clackmannan field to the north. The western area is occupied by the Ayrshire coalfield, with the small Sanquhar field to the south. The eastern area, comprises the Fifeshire coalfield to the north, and the Midlothian field to the south of the Firth of Forth. The relative importance of the different fields, may be gauged by their outputs, in 1924, which were :—

	Coal Raised Tons.
Fife and Clackmannan	8,411,441
Midlothian	4,312,824
Lanarkshire	18,498,006
(Anthracite)	454,220
Ayrshire...	4,513,790

The coal seams are discontinuous, not only when traced in the different areas, but in the same field, few seams being of wide lateral extension. Moreover, the fields are much cut by faults and the seams modified by igneous intrusions, which, in places, have produced the so-called " anthracites." Hence, a satisfactory correlation is impossible. The coalfields, as a whole, produce gas, house, and manufacturing coals, with some bastard anthracites and steam coals. Coking coals are, also, produced from restricted areas of the Lanarkshire and Ayrshire fields. Some coals, in these areas, are utilised for the smelting of iron-ores. In the Ayrshire coalfield, the coals produced are mainly of house, steam and manufacturing types, coking and gas coals being produced from the New Cummock and Dalmellington areas, from the seams of the Limestone Coal group. The most important seams are the Ell Coal, Main (house coal) and Ayr Hards, the Three Foot, Four Foot and Eight Foot forming coking coals.

The Lanarkshire Coalfield produces house, steam and manufacturing coal, and in addition, the bulk of the Scottish coking and " anthracite " coals. The north of the field, that portion included in Dumbarton and Stirling, produces the Kilsyth coking coal; coking and gas coals extend up to Stirling. The Main coal of the northern district is chiefly used for coking, the Splint coal provides an " anthracite " (locally), or steam coal, and the Lower Five Foot, a house coal, known locally as the Alloa Jewel. The coals of the central and southern part of the Lanarkshire field, produces mainly house, manufacturing and steam, with some coking coals, and, locally, coals, anthracite in type, produced from bituminous coal seams modified by igneous intrusions. The principal seams worked are, in ascending order, Lower Drumgray, Upper Drumgray, Kiltongue, Ladygrange, and Virtuewell, Virgin, Splint, Main, Pyotshaw and Ell. Seams, or bands, of " parrot " or cannel coal, are frequent.

The Fife Coalfield extends in a narrow belt, along the Firth of Forth, from Lochty westward for 30 miles. The coals worked are mainly house, steam and manufacturing coals, with some gas and semi-anthracites. The chief seams worked, are the Dysart Main and Chemiss in the Dysart-Leven area. To the west of the area, the Dunfermline Splint, Lochgelly Splint, Swallowdrum, the Eight Foot and Five Foot are of importance.

The Lothian Coalfield, south of the Firth of Forth, extending east and south-east of Edinburgh, produces mainly house and steam coal. Many of the seams contain bands of cannel and splint coal, the cannel, in certain districts, making the seam of special value.

The principal seams are the Great, which is, frequently, associated with Parrot coal, the Diamond and Jewel, which provide house coals. In addition, the Three Foot, Four Foot and Five Foot are worked.

Chapter 2.

LOSS OF COAL IN MINING.

By Prof. Douglas Hay, M.Inst.C.E.

In working any mineral deposit, whether metal vein or coal seam, some loss of product is inevitable; 100% extraction is not possible. Sometimes this loss is deliberate; for instance, in loading up the mineral in the process of mining it is found that certain portions are inferior and not worth sending out of the mine to the dressing plant. Again, the exigencies of surface support, and other practical considerations, inhibit the mining of certain areas. Yet again, certain deposits or portions of a deposit, are so inferior as not to be worth the trouble of mining; in this way entire coal seams have been abandoned, or left unworked.

Every colliery manager anxiously examines the physical and chemical conditions of the limited coal reserves of his mine in the endeavour to increase his output, lower his costs, and prolong the life of his mine. In general he will send out of the mine all workable coal which will bear the cost of dressing for the market. The requirements of his market therefore limit his activities in this direction.

These various causes of loss may be discussed under two heads. First: The leaving of mineral in the mine, in the process of working; and, second, leaving *in situ* inferior seams or inferior portions of seams in the process of mining. The first may be sub-divided as follows:—

(1) The leaving of pillars to support the surface.

(2) The leaving of coal in barriers.

(3) The rejection of inferior coal and dross during the process of loading at the face.

Leaving coal in pillars for surface support.

The owner of the surface has always been entitled of common right to support for his property, and until the early part of the 19th century permission to lower the surface was rarely given. In shallow seams, narrow pillars were left in the early days of mining, but as mines increased in depth wider pillars became necessary until almost half the coal was left in the mine unworked. It was also considered dangerous to remove the pillars, but about 1830 improvements in the method of working and increasing scientific knowledge brought about the systematic working out of pillars. At a later period the introduction of the longwall system led to the complete removal of the seam in one operation. It has since been found that by systematic longwall working with good packing, several seams can be worked out completely under property, lowering it by several feet with little or no damage.

Nevertheless, pillars are usually and advisedly left under large and important buildings or works,the size of such pillars being determined by experience. No estimates are available of the national loss sustained in this way, but it, undoubtedly, forms an appreciable part of our total coal reserves. Whilst such loss is frequently unavoidable it is a matter for regret that even at the present time the injudicious siting of building schemes and public works is causing the permanent loss of valuable minerals. The careless and arbitrary action of local authorities is in the writer's experience, frequently the cause of such losses; had proper enquiry been made of the colliery managements, other sites could have been found which would not entail the locking up of valuable coal.

Leaving coal in barriers.

This source of loss seems recently to have caught the public eye, and whilst it is true that the exigencies of ownership, and the law of trespass, have undoubtedly in the past caused a large and unnecessary loss in coal left in barriers, yet there remain many cases where barriers must be left in order to ensure safety in working. The principal reason for leaving barriers is found in cases where there is risk of flooding from water in adjacent abandoned workings or from the outcrop of seams and in such cases the leaving of adequate barriers as an insurance cannot be too strongly insisted upon. Again, in the case of seams liable to spontaneous combustion it may be advisable to leave fire barriers, not only between adjacent mines, but also between districts within the individual mine.

The recent tendency towards amalgamation of small undertakings will, undoubtedly, result in the extraction of certain barriers that would otherwise have been left. No colliery company will leave coal in any barrier if it can safely and economically be removed.

Rejection of inferior coal and dross in working.

Public attention has also been drawn to the deliberate leaving of coal during the working of a seam, in consequence of a certain proportion of the coal mined being rejected by the colliers and thrown back into the " goaf," or " waste." Under this heading may be included inferior portions of " bands " in the seam itself, the small coal (generally admixed with shale) comprising the " cuttings " from coal-cutting machines, and even in certain cases the leaving of the smaller size of coal, the larger or " round " coal only being filled out.

Now it may be taken as an axiom that no colliery manager will deliberately leave coal in the mine without good reason, for he desires to obtain maximum extraction and maximum output for a given amount of " face " room. The reason for this loss is therefore the economic one, that such " coal " does not obtain a market price sufficient to pay for the labour and other costs involved in bringing it to the surface. The principal reason for this is that the ash content of the portions of the seam comprised under this heading is too high for market requirements, and, unfortunately, the percentage so lost is steadily increasing in consequence of the thinness and dirtiness of the seams, which are being worked to-day, as compared with the thick and clean seams of a generation ago.

In his Cantor Lectures at the Royal Society of Arts in 1925, Dr. Lessing criticises the action of the collieries in this respect, and suggests that all this " coal " should be sent out of the mine, and then cleaned down to a reasonable ash content which must not be less than 10% to meet British requirements. Admittedly, there may be, at times, as much as 85% of coal in the material thus left underground, but, unfortunately, with our present design of commercial washing plants the cost of reducing the ash content to a reasonable figure would be prohibitive. Usually, moreover, it would be necessary to crush the material finely in order to separate the impurities from the coal and the final product would consist largely of very small coal particles which are now a drug on the market. To make matters worse, commercial washing plants are notoriously inefficient in dealing with the fine coal. The writer estimates that to adopt Dr. Lessing's suggestion would involve a loss of at least 7/- per ton on all the coal of this class that might be sent out of the pit instead of being rejected, and it may pertinently be asked if this is a reasonable type of " reorganisation " to ask collieries to undertake.

Far more to the point would it be to ask why this country refuses to utilise inferior qualities of coal containing up to, say, 30% of ash when methods exist for utilising it in its natural state economically. The writer will pursue this inquiry later in dealing with the other major cause of loss of fuel.

It may, also pertinently be asked why there is such a poor market for small coal even if its ash content be low. British consumers insist on a large proportion of round " coal " and this alone obtains a price remunerative to the collieries, whilst the large proportion of slack duff or small coal is now sold at a loss. Yet the calorific value of such slack may be equal to that of the large coal and methods of utilisation exist (i.e., pulverised fuel boiler firing) whereby such a fuel may be efficiently used. It follows that if the market could be persuaded to utilise this class of fuel, it would pay the collieries in many cases to bring it to the surface.

LEAVING *IN SITU* INFERIOR SEAMS OR INFERIOR PORTIONS OF SEAMS.

Most British coal seams are composite, i.e., are made up of two or more layers of coal of different chemical and physical characteristics. At the two extremes we may have either a seam the whole of which is acceptable to the market, and which is, therefore, entirely extracted, or else we may have a seam no part of which is merchantable. Yet, this latter seam may contain 90% of combustible matter, and have a high calorific value.

Similarly, between these extremes we find composite seams, parts of which are merchantable, while other parts are not and must be left unworked.

Taken altogether an unknown but substantial percentage of the nation's fuel resources is being lost in this manner, added to which we have the deliberate rejection of small coal during the working of the better seams, as has been outlined above. It is clear that at present collieries could not obtain an adequate return for the cost of mining and dressing such fuel to market requirements, but it is germane to this discussion to ask why such fuels could not be utilised in their natural state, so saving the nation the heavy expense of dressing them to market requirements.

The answer is that many of these inferior fuels can and, in a few cases, are being utilised for steam raising and other industrial purposes by pulverised fuel firing or by special types of grates and furnaces. The objection (raised by Dr. Lessing in his Cantor Lectures) to the cost of carrying large quantities of inert material (ash) long distances, is met by employing such fuels at or near the pit-head.

The interesting purpose of such a mode of utilisation, together with the utilisation of the waste heat and gas from coke ovens, etc., and other sources of waste heat at collieries has been fully discussed by the writer elsewhere (Inst. Civil Engineers, January, 1927, " The Production and Utilisation of Power at Collieries "), and it will suffice here to say that it would be possible to produce electricity in colliery power stations at figures much below those obtainable, at present, from public supply companies. For years past collieries, themselves, have generated electric current from such fuels, and have found that it pays them to produce current for their own requirements in this way.

Some of these reserves of inferior coal consist of gas and coking coals, and the day will come when processes will be developed to carbonise such coal in order to extract oil, gas and other by-products, the semi coke resulting being utilised as pulverised fuel for steam raising.

Alternatively, complete gasification may be resorted to, but, at present, this country lags a long way behind the Continent and the U.S.A. in the production and utilisation of gas from coal on a large scale. In the National interest a scheme should be drawn up to provide for a complete system of interlinking gas mains into which gas made at many collieries, both in coke ovens and in other ways, may be passed. In the writer's opinion the traditional system of isolated individual gas works, obtaining their raw coal from collieries many miles away will give place to a national scheme intended to utilise all available resources of cheap gas supply.

In the various ways outlined above, use can be found for the inferior fuels at present rejected in the mine or left unworked, without involving the high cost of dressing required to bring the fuel up to the arbitrarily high standard required at present by consumers. In a few instances, this has been realised, but, generally speaking, the utilisation of such fuels is left to the collieries themselves as a part of their internal economy. Sooner or later, however, this question will force itself into public notice with the diminution of our coal reserves, and the increasing necessity of reserving the best and cleanest for such purposes as the production of industrial coke and domestic fuels.

Given a market for coal of varying degrees of size and purity it may be taken for granted that mining engineers will exert their utmost efforts to reduce the loss of fuel in mining to a minimum.

Chapter 3.

POWER PRODUCTION AND UTILISATION AT COLLIERIES.

By J. Sinclair, M.Eng., and Prof. I. C. F. Statham, B.Eng., F.G.S.

No branch of mining engineering presents a wider range of possibilities, or a greater diversity of practice, than that of power production and utilisation. Not only is this true of the mining industry as a whole, but in individual coalfields, power schemes vary to an enormous extent, and the reasons for such variations are not far to seek. The depth of the seam, or seams, from the surface, the presence or absence of water, the natural conditions of the seam, or seams, their inclination, thickness and hardness, the amount of gas given off from the coal (which largely determines the kind of power to be used underground, whether compressed air, or electricity, and also influences the ventilating power requirements), all have their effect upon the power requirements of a mine. Furthermore, the sources of power available vary enormously and lead to the adoption of widely differing methods of power production. It will thus be seen that the power problem at any mine is, and must always be, an individual one, as no two collieries exhibit the same characteristics, either in respect of the amount of power required, or the availability of power, so that a scheme admirably suited for one case may fail lamentably to meet the requirements of another mine.

The problem of power at collieries is important, both from the standpoint of possible economies in the expenditure of our wasting national fuel resources, and from the possible reduction in the cost of production of coal.

The power performance of collieries is, frequently, expressed by the percentage of the total coal raised, which is consumed for colliery purposes. But, unless an indication is given of the precise character of the fuel employed, together with details of the power scheme in operation, such a statement is meaningless. Thus, a colliery using a low grade fuel, of comparatively low market value, may consume a relatively high percentage of its output, and still be working more economically than another colliery, using a lower percentage of high grade fuel having a high market value, together with costly plant designed to obtain a maximum thermal efficiency from such fuel. It thus appears, that the only criterion as to the efficient generation and utilisation of power, is the cost of such power, per ton of coal raised, or, alternatively, the kilowatt hours consumed, per ton, which may be readily converted into terms of its monetary

Table I.—Percentage Consumption of Various Coalfields, Sept. 1923 to 1924.*

Scotland	8.98
Northumberland	4.15
Durham	2.99
South Wales, Monmouthshire	6.04
Yorkshire, Leicester, Nottingham, Derby, Warwickshire, Cannock	5.48
North Wales	9.80
Lancashire, Cheshire, North Staffs.	8.96
South Staffs, Salop.	8.61
Cumberland	8.54
Bristol	6.63
Forest of Dean	9.85
Somerset	7.56
Kent	14.00
Average for the whole of Britain	6.13

* J. F. Perry. World Power, December, 1925.

equivalent. In other words, percentage consumption and thermal efficiency must be considered in the light of commercial efficiency, or cost of power, per ton raised, which will vary with the conditions prevailing at the individual mine.

Whilst the percentage consumption can only be taken as a very rough indication of the power efficency of collieries, it is of interest to compare the figures for the various coalfields, and to ascertain the approximate average for the United Kingdom. These are given for the year 1923-24 in Table I.

With an annual output of about 260,000,000 tons, per annum, the amount of coal burnt at collieries, thus amounts to, approximately, 16,000,000 tons per annum, the value of which at 10s. per ton is £8,000,000.

The power requirements of individual collieries, may vary from 4 to upwards of 50, kilowatt hours, per ton, raised. Nor is the amount of power thus stated, indicative of the efficiency, or otherwise, of the colliery plant, as a high power consumption may be due to a variety of causes, such as a highly mechanised state of affairs in a gassy mine, where compressed air is largely used, or to a heavy and unavoidable pumping load.

Table II*, gives the average consumption of energy, per ton, raised for Great Britain, based upon data collected from a number of all-electric pits of various classes, in different districts.

TABLE II.

South Wales	32
	25
Newcastle	21.5 (average of 6 pits).
	8.15
	7.5
Yorkshire	12.0
Average for Great Britain	17.0
French Pits. Pas de Calais	13.5
Wencelaus Mine, Germany	15.3

POWER PRODUCTION.

Sources of power available.

In considering the question of power production, cognisance must be taken of the variety of fuels, and other sources of power available at, or near the pit head, and, as a preliminary to the discussion of the various schemes in operation, it is necessary to examine, briefly, the possible sources of power.

Such potential sources of power, may be conveniently classed under the following heads :—(1) Relatively high value washed slack; (2) Ordinary unwashed slack; (3) Inferior fuels including (*a*) Fines with high ash content. (*b*) Low grade fuels normally left unworked; (4) Coke-oven gas; and (5) Waste heat from coke ovens.

The characteristics of the above fuels, etc., may be, briefly, summarised as follows :—

(1) Relatively high value washed slacks usually have an ash content below 10 per cent., and a calorific value of 11,000 to 14,000 B.Th.U.'s per lb. Their market value varies from time to time, but is, usually, sufficiently high to enable them to be sold with a margin of profit. It will be agreed, that the amount of such fuel used at mines should be a minimum, especially when account is taken of the amount of lower grade fuel available, the high ash content and heavy transport charges of which, precludes the finding of a market, except in times of emergency, such as that created by a prolonged coal stoppage. Under certain circumstances, however, the use of such a fuel may be justified as in the case of a Lancashire

* J. F. Perry. World Power. The figures for Wencelaus Mine, Germany, have been added.

boiler plant, which must be worked to its utmost capacity, and where the installation of a larger and more modern boiler plant is considered to be inadvisable, on account of the limited life of the mine. In such cases, the only economical method of meeting the requirements, and of keeping the steam pressure up to normal, may be by the utilisation of a high-grade fuel.

(2) Ordinary unwashed slack may have an ash content of 10 to 40 per cent., and its market value may be anything from zero to 6s. or 8s. per ton. Probably, the best medium for the utilisation of such fuel is a water-tube boiler plant, with chain grate stokers. The steam reserve of this type of boiler has been questioned, but for a group power station, where the diversity factor is good and peaks are smoothed, by the varying demands of the individual collieries, the question of steam reserve does not arise. In the case of a self-contained colliery, unless the winding load is exceptionally high, and comprises above 40 per cent. of the total load, the water-tube boiler will be found to afford adequate reserve. The choice of boilers is, however, affected by the quality of the feed water available, and not infrequently, Lancashire boilers are installed for no other reason than that of the impurity of the local water supply.

(3) Inferior fuels with high ash content.

There are few collieries at which such fuels are not available in considerable quantity. (*a*) In the first place, mention may be made of the fine coal produced in the normal course of events. The usual practice in the past, has been to recover these fines from the washery, in the form of slurry. This may be allowed to drain, and can then be used as a boiler fuel, a practice which has frequently been adopted. Such fuel may contain from 10 to 40 per cent. of ash. This fine coal, probably, constitutes the most objectionable proportion of the mine output, as it contains high percentages of fusain and sulphur, both of which adversely affect the value of the coal for coking purposes, and, furthermore, its ash content is invariably high.

The difficulties of effectively washing, and, later, of utilising the fines, have led to the practice now adopted at a number of collieries, of taking out from the slack, before washing, all which passes through an $\frac{1}{8}$ or $\frac{1}{16}$ inch mesh screen. This product is then pulverised, and used as powdered fuel for the raising of steam in water-tube boilers.

The adoption of powdered fuel involves expenditure in pulverisation, and, may also necessitate the drying of the coal before pulverisation, but, results, so far obtained, indicate that this method of power production is efficient and economical.

(*b*) In addition to the low-grade fuels already mentioned, the utilisation, or disposal of which faces every colliery, large quantities of low-grade fuel are, frequently, found in association with the seams of coal as worked, but which, on account of their low value, are left in the mine. These comprise, so called "bad coal" bands, coal cutter holings or "gummings," and, in the case of house coal pits, where only large coal is allowed to be sent out of the pit, the majority of the slack produced in the operation of coal getting. Such materials are, usually, disposed of underground, by throwing them into the goaf when they are irretrievably lost, whilst, in many cases, bands of inferior coal, immediately adjacent to the seams as worked, either below or above, are left unmined and are thus similarly lost. At the present time, few possibilities exist for the utilisation of these low-grade fuels, which could probably be raised at a cost of 5s. to 6s. per ton.

When we consider that this country possesses only about $2\frac{1}{2}$ per cent. of the total coal resources of the world, and that we are producing something like 20 per cent. of the world's output, it is, at once, apparent that every step should be taken to husband our resources, and to reduce waste in use, and loss in working to the absolute (economical) minimum. With transport charges at their present high level, it is not suggested that such low-grade fuels might be transported far from the pit, as this would involve waggons carrying a quarter to half their capacity of incombustible matter. It would, however, appear that a case could be made out for the utilisation of these low-grade fuels to a much greater extent than at present, and, there is no doubt, that the place for such utilisation is at the collieries, where they are mined.

For such solid fuels, Lancashire boilers are most commonly used, but the water-tube boiler is being increasingly employed, especially where low-grade fuel has to be burned by mechanical stokers, or, where pulverised fuel is used. On the Continent, the water-tube boiler is much more common, especially where

the steam consumption of the winder, is only a small fraction of the total steam generated, and where great flexibility of evaporation is not essential.

(4) Coke-oven gas.

A large percentage of the collieries producing coking coals have, working in conjunction with them, batteries of coke ovens and by-product plants, owned by the colliery company, or a subsidiary company. The majority of the newer coking plants use regenerative ovens, which yield a considerable amount of surplus gas.

Only about 50 per cent. of the total gas yielded by the coal is employed in heating the ovens, the remaining 50 per cent. (some 5,000 cubic feet of gas per ton carbonised), is available for extraneous use (including power and steam requirements of coke-oven and by-products plant). This gas has an average calorific value of about 475 B.Th.U.'s per cubic foot, and the surplus gas from a large modern coking plant contains an enormous amount of potential thermal energy, which may be utilised in a variety of ways.

Thus, it may be disposed of by sale to a gas company, who resell it for domestic or industrial use. Provided that reasonable terms can be arranged, this is, probably, the most economical method of disposing of the gas. If, however, facilities for disposal in this manner do not exist, the gas may be utilised, either in gas engines, or may be burnt in gas-fired boilers. The early attempts to use coke-oven gas, in gas engines, presented certain difficulties which militated against their general adoption. One of the principal difficulties in this direction, was due to the high calorific value of the gas, necessitating its dilution by hot exhaust gases, which gave rise to trouble on account of their corrosive action upon the engine parts. Improvements have, however, been made, whereby separate air and gas controls are possible, and the dilution, by hot gases, is no longer necessary. At the present time, vertical gas engines up to 1,200 H.P. are proving reliable and doing good work, consuming about 30 cubic feet of coke-oven gas, per kilowatt hour developed.

The use of coke-oven gas for boiler firing, was, until recent years, a somewhat inefficient means of power production, owing largely to the fact that attempts were made to use the gas in boilers designed for solid firing, such as the Lancashire boiler, or the ordinary water-tube boiler. Improvements in the design of the latter type of boiler, and the introduction of the fire-tube boiler have, however, solved the problem of gas firing. The Kirke fire-tube boiler has a high efficiency, can be used for live gas or waste heat, and has the additional advantage of quick steam raising.

(5) Waste heat from coke ovens.

Although the present tendency is to instal regenerative coke ovens, there are still in existence a large number of waste heat oven plants. Such ovens yield, relatively, small quantities of live gas (from 5 to 20 per cent.) but the hot products of combustion are available for steam raising. These hot gases may be utilised in Lancashire, water-tube, or fire-tube boilers. The first-named type of boiler yields a, comparatively, low efficiency, but the fire-tube boiler will yield up to 50 kilowatt hours, per ton of coal carbonised, per hour. A serious disadvantage of the waste heat type of oven is that the surplus stores of waste heat cannot be stored, or transported, hence they must be used continuously and near the coke ovens.

Power schemes in use.

For colliery purposes, three kinds of power are applicable, viz., steam, electricity, and compressed air, and the widely varying degrees to which each is employed, renders difficult the discussion of the problem of power schemes within the compass of a short study. The principal consumer of power, at the average colliery, is the winder, which may be steam or electrically operated, but, in considering the question of power from a general standpoint, it is necessary to take into account other requirements, including ventilation, pumping, underground needs for haulage, coal cutting, conveying, etc., and such auxiliary services as screening, etc.

The extent to which electricity may be used for underground work, will depend upon the character of the seam, or seams. If these are gaseous, it will be necessary to resort to the use of compressed air for inbye power purposes, and this compressed air may be developed from steam, or electricity.

The primary consideration, however, resolves itself into a decision, as to the relative merits of steam and electricity for the main power consuming purposes, viz., winding, ventilation, and underground use. For present purposes, attention may be confined to 3 phase A.C., which is almost exclusively employed, nowadays, on account of its convenience in generation, transmission, transformation, and additional safety for mining purposes.

Of late years, great controversy has raged around the question of steam versus electricity; much has been said and written, both for and against both methods of power production, and costs have been put forward in support of the claims made, by the two conflicting schools of opinion. From the available evidence it would appear that a field exists for both steam and electricity, but there is little doubt that the field for electricity is ever widening and will tend to do so, increasingly, as various grouping schemes, now so much to the fore, are adopted. The position may be summed up, briefly, as follows:— For individual collieries, or collieries where modern and efficient steam plant is already installed, steam winders, steam-driven fan engines, and conceivably steam-driven compressor engines, supplying exhaust steam to mixed pressure turbo-generators, is the most common, and is, probably, the cheapest power scheme that is available.

It must, however, be recognised that mixed pressure turbines are inefficient when running on high-pressure steam, so that it is essential that the winding, ventilating, and compressing (if any) load, should be large compared to the rest of the power load, otherwise, the amount of high-pressure "make-up" steam required at the turbines, will greatly increase the power costs. The ratio of the winding, ventilating, and compressing load, supplying low-pressure steam, is an important factor in deciding upon the type of power scheme. If these three supply just sufficient low-pressure steam to meet the needs for pumping, haulage, lighting and surface works, and these are electrically driven, a case can usually be made out for steam winder, fan engine, and compressors, with mixed-pressure turbines for supplying power for auxiliary purposes.

Passing now to consider the larger unit, the power station for a group of collieries; here, the conditions approach nearer to those of public utility supply stations, and the efficiencies obtained in such group power stations, are comparable with those of public supply stations. Furthermore, the diversity factor, by smoothing out peak loads, reduces the amount of stand-by plant required, expressed as a percentage of full rated demand. One of the most up-to-date group power stations in this country, is the Powell Duffryn Plant, at Bargoed, which supplies high-tension current and compressed air, via large mains, to the surrounding collieries in the Rhymney Valley. The boiler plant at this station, consists of ten Babcock and Wilcox boilers, with chain grate stokers and balanced draught, arranged to burn washed bituminous duff, or coke breeze, either separately, or together by blanketing. The steam pressure is 350 lbs., per sq. inch, at a temperature of 700° F. From routine tests, the average operating efficiency of the boiler plant is 81.8 per cent., although efficiencies as high as 89 per cent. have been recorded.

The electrical generator equipment, consists of three turbo-alternators, having an aggregate capacity of 34,000 K.V.A., at 11,000 volts, which is transformed to 33,000 volts, at which pressure it is fed into a link main for transmission to the collieries, the main being interlinked with other stations, at individual collieries. In order to minimise the risk of breakdown each colliery is served by, at least, two feeders.

The compressed air plant comprises three eleven-stage turbo-compressors, each having a capacity of 40,000 cubic feet of free air, per minute, and compressing to 80 lbs., per sq. inch. These compressors feed into two-feet diameter mains which serve the collieries, existing electrically-driven compressors at the collieries also feeding into the mains and acting as boosters, as and when required. The load factor is high, being 70 per cent., due to the heavy coal cutting and pumping loads on the night shift, at the various collieries. By careful attention to the design of the air mains, balancing capital cost of installation, against losses due to frictional resistance for various sizes, and, thus, finding the most economical size of main, it is claimed that power may be conveyed more cheaply by compressed air, than by electricity, for distances up to 5 miles. Beyond this distance, it is probable that electrically-driven compressors, at the individual collieries, would be more economical than a central compressing plant.

While the efficiency of power transmission by compressed air may, under ideal conditions, be equal to that of electricity, the low efficiency of utilisation of compressed air, which is inherent in this method of transmitting power, makes the cost of compressed air, per unit of power, usefully employed, greater than is the case with electricity. The Powell Duffryn Station, probably, represents the ideal practice for a large colliery group, and the circumstances which led to its erection are not likely to occur in many cases, but several of the grouping schemes in contemplation, are tending in that direction, and where large groups of collieries, with like needs, have to be provided for the experience at Bargoed will be of great value.

Another central power scheme for a group of collieries, deserving special mention, is that of the Carlton Main Collieries, near Barnsley. A large central power station, at Frickley Colliery, supplies power to several of the South Yorkshire collieries connected with the company.

On the Rand, a similar station supplies electricity and compressed air to a group of gold mines in the area.

It has already been stated that, under certain conditions, electricity offers advantages over steam for colliery purposes, and the relative merits of generation, as compared with the purchase of power from a supply company, may now be considered. The problem resolves itself into one of £ s. d., and the final decision must be governed by comparison of the cost involved in each case. Generally speaking, if power can be purchased at less than ½d. per unit, it will prove more economical to purchase than to generate, as, although power may be generated at the colliery at a less cost, due allowance must be made for interest on capital, depreciation of plant and stand-by losses, which are large if the reserve provided is to be at all adequate to meet the needs. It will be obvious that where power is purchased, the colliery company is not faced with so large a capital expenditure, but the low power factor, and the poor load factor, usually inseparable from colliery plants, often result in the inclusion of penalty clauses in the power contracts, which increase the cost.

Much may be done to reduce the total power costs, by the installation of machines, or devices for power-factor correction, thus ensuring that the power factor is at a maximum, and by even distribution of the load over the 24 hours, as far as possible. Considerable improvement in the load factor may be wrought by arranging for coal cutting and pumping operations to be performed, as far as practicable, on the idle shift when coal is not being wound.

A noteworthy innovation in colliery power practices has been introduced, in the last few years, at a large new Nottingham colliery, where power for auxiliary, and other steady loads, including ventilation, is purchased from the local power supply company. For winding, a modified Ward-Leonard system, known as the Stubbs-Perry system, has been adopted, in which a high-pressure turbine with fly-wheel to equalise the steam demands, has been substituted for the A.C. motor driving the motor generator equipment. Steam for the turbine plant is supplied from Babcock and Wilcox boilers, which are "banked" during the non-coal winding shifts, when men are lowered by current from the power company, but as the peak loads are low, this does not incommode the power company.

THE UTILISATION OF POWER AT COLLIERIES.

Passing now to consider the various purposes for which power is required at collieries, we find, again, a wide variety of conditions met in a number of ways.

At the majority of collieries, especially the more modern and deep ones, the largest individual load is that due to winding, and the type of winder adopted has considerable influence upon the method of generating power for the remainder of the load. The winding load varies with the depth, the output per shift, etc., and the energy consumed, per ton raised, may range from 1 to 10 units, representing anything from 12 per cent. to upwards of 40 per cent. of the total consumption at the colliery.

As already indicated, great controversy has raged and keen discussions have taken place over the relative efficiencies of steam and electric winders, and investigation shows that there are instances where steam winders are the correct type to instal, while in other cases, electric winders are, undoubtedly, more economical. Both systems are extensively employed, but, of late years, there has been an increasing tendency to resort to the use of electricity for winding. The following is a brief summary, of the salient characteristics of the two systems, as usually employed.

Steam Winders. In this country, the simple two-cylinder, horizontal type is, generally, preferred to the more complicated but more efficient compound engine, on the score that economy may, legitimately, be sacrificed to some extent to simplicity and reliability, in such an important operation as winding. For heavy loads and deep shafts, however, cross compound and double tandem compound engines are frequently installed. In Germany, the four-cylinder tandem compound engine, with the exhaust connected to a central condenser is the standard type.

Where compound engines are used, it is customary to introduce a steam jacketed receiver between the high-pressure and low-pressure cylinders. To ensure that steam is always available in the low-pressure cylinders, this receiver is fitted with a reducing valve for the admission of live steam. Vertical winding engines are still to be found in a few of the older collieries, and may still be installed where lack of space precludes the adoption of horizontal cylinders. The steam consumption of winding engines is usually rather high, varying from 30 to 60 lb. per I.H.P., the latter high figure referring to older engines with large clearance volumes. On large winders, valves of the drop valve type are more generally used, but Corliss valves are, often, used on the exhaust. Central condensing plant, into which the winding engines and other steam engines exhaust, are not common, owing to the preponderance of the winding load, which gives a very fluctuating delivery to the condenser.

Electric Winders. There are two main types of electric winders in use, namely, those operated by A.C. motors, and those operated by D.C. motors. The former type, known as the straight A.C. drive, usually consists of a slip ring induction motor, geared to the drum shaft and supplied, directly, from the A.C. mains, while, in the latter type, the D.C. winding motor is usually supplied from a motor generator set, either with or without a fly-wheel, the speed control being obtained on the Ward-Leonard principle. While this broad classification is not quite complete, it covers the majority of cases, and must suffice for present purposes.

The Ward-Leonard system, in its simplest form, includes an induction motor, which drives two D.C. generators, one supplying the field for the winding motor, and, through a rheostat, the field for the second generator, which supplies the E.M.F. to the winding motor. The speed of the motor depends upon the E.M.F. generated by the second motor, which, in turn, depends upon the strength of the field. This is regulated by the position of the contact arm on the face plate type controlling rheostat. By connecting the contact arm to the depth indicator, the control of the winder is rendered practically automatic, the rate of acceleration being definitely fixed, and arrangements made for returning the contact arm to the off position at the end of the wind.

Regenerative braking may be employed, and power is returned to the D.C. mains. The ease and simplicity of control of the Ward-Leonard system, make it ideal from the safety and driving point of view. The acceleration peak is, gradually, applied and is not sustained. The ease of control, and the light rheostatic losses, make it very suitable for short fast winds. The capital outlay is much greater (50 to 75 per cent. in excess) than that for an A.C., or steam winder of the same power. The motor generator losses continue during the decking periods, and, also, during standage, which is a great disadvantage where the delivery of coal to the pit bottom is spasmodic.

In some cases, a synchronous motor, taking leading current, has been employed in place of the usual induction motor, for driving the motor generator set. By this means, the power factor of the colliery, as a whole, may be improved. An efficiency of 61 per cent.* has been obtained with an equipment of this type.

Alternative methods of drive are, also, occasionally employed as in the case of the Stubbs-Perry system, previously mentioned, where a high-pressure, condensing turbine is used having a fly-wheel to equalise the steam demands on the boiler, and an eddy current brake for regenerative control. In other cases, gas engines have been used to drive the generators.

The D.C. winding motor is, generally, coupled direct to the winding drum, as slow speed D.C. motors are found to be quite efficient.

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* E. I. David. Journal of Institution of Electrical Engineers, June, 1925.

In the Ward-Leonard Ilgner system, a heavy cast-steel fly-wheel, frequently cased in to reduce windage losses, is attached to the motor generator shaft, in order to equalise, as far as possible, the current demand on the A.C. mains, and thus prevent the occurrence of heavy peak loads on the generating station. This is accomplished by the employment of a slip regulator, which inserts resistance into the rotor circuit of the induction motor driving the motor generator set, and, thereby, limits the current taken from the A.C. mains, and, by reducing the speed of the motor generator set, allows the fly-wheel to give up its stored-up energy. During the retardation and decking periods, the motor generator set regains its full speed. Complete equalisation is seldom obtained, as the fly-wheel would be too heavy and its losses too high. Fly-wheels up to 12ft. 6in. in diameter, weighing up to 30 tons, are to be found on large winders.

The losses in the fly-wheel, and the comparatively low efficiency of the induction motor, due to its variable speed, result in reduced efficiency of the Ilgner set, as compared with the straight Ward-Leonard equipment, a typical efficiency being about 47 per cent.

The fly-wheel is commonly connected to the motor generator shaft by a clutch, so that it may be dispensed with when winding men, etc.

Pumping. The amount of water to be dealt with in coal mines is extremely variable; in some cases, little or no water is present, while, in others, the weight of water to be raised, may amount to six times that of the coal. The energy consumed for pumping may, therefore, range from 0 to 10 units, and the pumping load may represent anything from zero to 25 per cent. of the total load. Generally speaking, the newer and deeper pits are not seriously troubled with water after sinking operations have been completed, as the water, usually, occurs in the newer and upper measures, and may be, effectively, sealed back in the shaft, but the majority of British collieries are saddled with a greater or lesser pumping load.

As might be expected, a great variety of types of pumping plants are to be found in use, but the present day tendency is to instal multi-stage centrifugal, or turbine pumps. The efficiency, reliability, compactness, and low cost of upkeep of this type of pump, together with the fact that its high speed permits of direct coupling to an electric motor, make it particularly suitable for mine pumping, and, consequently, it has largely replaced other types.

For small loads, squirrel-cage motors are found to be quite satisfactory, but for driving large pumps, slip-ring motors are preferable, and it is not often thought to be worth while to instal synchronous type induction motors. The old beam pumps, so common in past days, although efficient when operated by multiple expansion condensing engines, have almost entirely disappeared on account of their bulk, high initial cost, and expense in maintenance.

For gathering work inbye, small, portable, direct-acting or three-throw ram pumps, driven by compressed air are usual. Electric drive is also common.

Ventilation. The standard type of ventilator is the centrifugal fan, of which there are numerous types in use.

The power required for ventilation, depends largely upon the character of the seams, whether gassy, or otherwise, and is influenced by the thickness of the seams wrought. The energy consumed varies with the conditions from 1 to 6 (or more) units, per ton of coal raised, and may represent anything from 7 to 40 per cent. of the total energy consumption at the mine.

The fan may be driven either by steam, or electricity. For steam driving, compound engines are frequently employed, and it is usual, in this country, to utilise the exhaust steam from fan engines in a mixed pressure turbine. Owing to the, practically, constant load required for ventilation, fans are admirably suited for the application of electric drive, as they serve to improve the load factor, and in A.C. systems, the use of synchronous salient pole and induction motors giving a leading power factor, may be adopted for power factor rectification.

Air Compressing. The increasing need for some safe form of power for use at, or near, the working face, has led to the extensive adoption of compressed air in mines. The recognition of the potential dangers of electricity, naturally gave rise to prejudice and opposition to its use in gassy mines.

In the early applications of electricity to underground work, such prejudice and opposition was well-founded, but, with our increasing knowledge of the requirements of flame-proof design of underground

electrical machinery, provided it is properly installed, maintained, and worked, need no longer be regarded with suspicion, and its more general adoption would lead to considerable economies in power utilisation.

It has already been stated that under ideal conditions, compressed air may be transmitted for distances up to five miles with an efficiency equal to that of electricity, but, even under such conditions, the low efficiency of machines using compressed air makes it an expensive medium for power purposes. Generally speaking, about 25 cubic feet per minute, of free air, at 70 lbs. per sq. inch, are required, per horse-power, whereas, it takes only 1 horse-power to compress and deliver 5 or 6 cubic feet of free air, per minute, up to 70 lbs. per sq. inch.

Furthermore, the conditions prevailing underground are such as to render it impossible to maintain pipe lines in such a state of perfection, as to ensure the high efficiency of transmission which attaches to electrical transmission, and, it must be admitted that, in many cases, the results obtained fall lamentably short of what might reasonably be expected. Leakage losses are frequently very high, as high as 50 per cent. in extreme cases. With proper attention to maintenance and frequent measurement of leakage and other losses much may be accomplished and money so spent is amply repaid.

At the older collieries, the steam-driven horizontal slow speed compressor has been largely employed, but the enormous bulk and low efficiency of this type of machine have led to the adoption of vertical high-speed compressors, which may be driven by steam, or electricity, and the turbo compressor.

Electrically-driven, vertical high-speed compressors are frequently coupled direct to the motor, which may be of the synchronous salient pole, or induction type, to assist in power-factor rectification. For quantities up to about 8,000 cubic feet of air, per minute, such compressors are the most efficient, but where large quantities of compressed air are required, the steam turbine driven turbo compressor is, to-day, regarded as the most economical proposition. Turbo compressors are rarely made for capacities, less than about 8,000 to 10,000 cubic feet, per minute.

In some cases, reciprocating air compressors are driven by gas engines, working on coke-oven gas. In France and Belgium, electrically-driven vertical high-speed compressors are, generally, employed, but in Germany, the low-speed horizontal type still prevails, the exhaust steam being delivered into central condensers. Turbo compressors, driven by mixed-pressure turbines, utilising the exhaust from the winding engine, are also frequently seen on the Continent.

The compressed air load varies enormously, depending upon the degree of mechanisation adopted below ground, whether this is driven electrically, or by compressed air, and upon the standard of maintenance of the plant. In extreme cases, the energy consumed in air compressing, may amount to as much as 27 units, per ton of coal raised, and may represent as much as 60 per cent. of the total energy employed. Some of the up-to-date German mines,* consume as much as 5,000 cubic feet of free air, per ton of coal raised, and use up to 3 per cent. of the coal production, for the generation of compressed air.

Haulage. As in other branches of colliery engineering, a wide diversity of practice is to be found in haulage arrangements. The type of haulage adopted is, to some extent, affected by the inclination of the seam, or seams. No hard and fast rule may be given, but, speaking generally, in steep seams, self-acting and main rope haulages are, largely, employed ; while in flat, moderately inclined and undulating seams, endless rope, or main and tail rope, probably predominate. Main, or arterial haulages, are, generally, electrically driven by motors situated at, or near, the pit bottom.

For both main, and main and tail rope haulages, slip-ring motors, of one or two hour ratings, operated by liquid controllers and reversing switches, are largely employed. For endless rope work, squirrel, cage motors are sometimes adopted, and arrangements made to start the motor up with no load, the load being gradually applied, when the motor is up to speed, by means of some form of friction clutch, generally of the expanding type.

Secondary and gathering haulages, may be, either, electric or compressed air driven, and there has been a marked tendency, of late years, to substitute small haulage gears, in situations where the haulage was formerly performed by horses.

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* Dr. J. Herczegh. Sheffield University Mining Magazine, 1926.

Compressed air-driven haulages are almost invariably of the ordinary reciprocatory two cylinder type, with cylinders varying from 4 to 15 inches in diameter, depending upon the work to be performed. Recently, small compressed air haulages, having a turbine drive, have been introduced.

In some of the older collieries, haulages are operated by a steam engine on the surface, power being transmitted down the shaft by a "strap" rope carried in boxes or pipes, secured to the shaft sides. Such a strap rope may operate several underground haulages, serving different districts by driving a main shafting carrying surge wheels, which may be clutched in or out as required.

The old practice of carrying steam down the shaft, for driving steam haulage engines at the pit bottom, is rarely found in operation to-day. The use of locomotives, for underground haulage, has not been adopted to any considerable degree in this country, and it appears unlikely that they will ever become so popular as they are in America, where electric locos. are used, or in Germany, where both trolley electric and compressed air locos are largely used, the former, for main intake haulages, and the latter for gathering from the faces. As rivals to rope haulage, they do not compare favourably, from the chief standpoints of cost and reliability. There are, however, certain limited services for which locomotives offer distinct possibilities, such as, for gathering tubs in flat seams, and for riding men to and from work in special travelling ways. For such purposes, battery locomotives may, under certain circumstances, prove economical, and, quite recently, the question of employing such locomotives underground, has been brought to the fore by a competition for a prize of £1,000, offered by the late Mr. Charles Markham, for the best designed locomotive for underground use.

On the Continent, rope haulages are being employed much more extensively, where, hitherto, locomotive and horse haulages were common.

Coal Cutting. During the present century, material progress has been made in the application of mechanical coal-cutting machines, and the power requirements for this purpose have increased accordingly. In 1901, only 1.4 per cent. of the total output of coal produced in the United Kingdom was cut by machinery, but, in the year 1925, the percentage had risen to 20 per cent.

Coal-cutting machines are of four main types, viz.: the disc, bar, chain, and percussive types. Each type has its own particular field of application. The disc, bar, and chain types, may be driven by electricity or compressed air, the latter type of drive being the more common, on account of the greater safety of compressed air, in workings where inflammable gas is likely to occur. In 1925, there were 3,514 coal-cutting machines driven by compressed air, and 3,133 driven by electricity; the number of percussive machines in use, practically all compressed-air driven, being 2,195, so that, if these be deducted, more than 70 per cent. of the longwall machines, are electrically driven. Chain machines are the most popular type, 2,524 being in use in 1925.

The large amount of scientific and practical research, devoted of late years to the design of electrical machinery and apparatus, to meet the requirements of safety in inflammable atmospheres, has led to the introduction of flame-proof motors, control gear, and cables, suitable for use in situations where, hitherto, compressed air was, almost exclusively, employed.

In some cases, D.C. machines are employed, but the present day tendency is to instal A.C. plant throughout for mining purposes.

The earlier compressed-air machines were driven by reciprocatory engines, but turbine drives are now, generally, adopted, and are found to be much more economical in air consumption.

The amount of power consumed, per square yard cut, depends upon the nature of the holing. In electrical machines it varies from .20 to 1.12 kilowatts, per square yard cut. In compressed-air machines, the consumption of free air, per minute, varies from 450 to 850. For narrow work in bord and pillar pits, and for opening out in longwall pits, percussive machines are, extensively, employed. Such machines, are usually driven by compressed air, but of late percussive electric machines have been placed on the market.

In some cases, such machines are used to bring down the coal after it has been undercut. A recent development in mechanical mining is the introduction of the arc-wall machine, which is self propelling and runs in and out of the various working places, under its own power, being somewhat on the lines of the larger machines, used in the U.S.A.

It is unlikely that the loading machines or combined cutting and loading machines employed in the United States will be of much utility in this country, on account of the thinner and more densely timbered seams being worked.

Coal Conveyors. Another underground operation, which has been increasingly mechanised of late years, is that of conveying the coal along the working face and mine roadways. Conveyors are of two main types, viz.: the belt and shaker types.

For face work, the shaker type is the more popular, and such conveyors are, generally, 80 to 100 yards long, although, in some cases, conveyors in series are used for longer lengths. Shaker conveyors may be driven by compressed air or electricity. In the former case, a single cylinder air engine of about 10—12 H.P. is, usually, employed, while, in the latter case, an electric motor of, approximately, the same power is used. Shaker conveyors are also used for conveying coal along gate roads.

In some cases, belt conveyors are used for face work, but they are more popular for gate and trunk conveyor work; other things being equal, belt conveyors are best suited for an electric drive.

In some mines, gate-end loaders are being employed. These are fitted with a scraper chain, which lifts the coal to an elevated jib, for delivery into the tubs. Where the size of the roadways is rapidly reduced by crush, the use of such machines gives rise to trouble in maintaining sufficient height, but, under favourable conditions, their use may result in considerable economy in working costs. An innovation in coal face methods has recently been made in a Cannock Chase colliery, by the use of a short self-loading conveyor, which sweeps the coal along to the gate road, after it has been shot down. The results so far obtained appear to be highly satisfactory, but its economical application necessitates the existence of conditions, which are far from general in British coalfields.

Power for other Underground Purposes. In addition to the various underground operations so far mentioned, certain minor operations call for the provision of power underground. Amongst these may be mentioned, drilling and lighting.

Drilling in coal is, frequently, performed by hand-operated drills, but there is a tendency to replace hand drilling by the use of power drills, which may be operated, either by compressed air, or electricity.

The most common type of drilling machine in use to-day, is the air-operated hammer drill, which gives good service, under very varying conditions. Hammer drills take from 28 to 50 cubic feet of free air, per minute.

In certain cases where electricity, only, is available as a source of power, small portable, electrically-driven compressors are employed to supply compressed air for drilling purposes, on account of the greater flexibility and adaptability of such machines.

Recently, however, improvements have been made in rotary electric drills, and a number of these are now in use, and appear to be giving good service.

For underground lighting by electricity, which is usually confined to the pit bottom and the main roads, a small lighting transformer, transforming down to about 125 volts, is installed.

SURFACE REQUIREMENTS.

The power requirements at the surface of the mine, depend upon the output, and the procedure adopted in the preparation of the coal for the market. Wherever possible, operations are made automatic, and the surface arrangements of the large and up-to-date British mines are so well planned, that the number of persons engaged on the surface, as compared with the number underground, is lower in Great Britain than in any European country. The chief power-consuming operations may be briefly summarised.

Screening and Washing. The power requirements for coal treatment, or preparation for the market, are, largely, determined by the class of coal worked, and the markets for which the coal is prepared. In modern colliery plants, tipplers, screens, belts, elevators, etc., are all driven electrically, usually by individual motors. Similar means are employed for pulsating the washery water, and its circulation throughout the washing plant, by centrifugal pumps.

Coke Oven Plant. About 40 kilowatts are required, per ton coked, per hour, for driving exhausters, pumps, etc. These may be operated electrically, or by steam, and, in many cases, steam operation is preferred, on account of the necessity for providing steam for the by-product recovery process, which requires (for the semi-direct process) some 380 lbs. of steam, per ton of coal carbonised. This steam may be raised by waste heat, or gas-fired boilers, the surplus steam from which may be used to generate electricity, as already indicated.

Other miscellaneous power-consuming agencies include the workshops, saw mill, mortar mill, etc., which again are supplied with power through the medium of individual motors.

In some cases, colliery undertakings are supplying the adjacent villages with electricity, for lighting, heating, and cooking, at prices much more advantageous to the consumers, than those of public supply companies. At some of the recent collieries in Derbyshire, hot water is also supplied to the colliery village.

COLLIERY POWER IN FOREIGN COUNTRIES.

It is impossible, within the limited space at our disposal, to give a detailed comparison of power schemes in Britain, with those in foreign countries, and the following brief particulars of the salient features must suffice.

In France, colliery grouping for power purposes has been, extensively, adopted with great benefit. This has been largely made possible by the almost wholesale destruction of the French mines during the war, which led to the necessity for reconstruction, and by relieving colliery companies of inefficient plant and methods, cleared the way for modernisation and technical co-operation, based upon experience gained in many parts of the world.

The reconstructed pits are completely electrified, and the average energy consumption, as shown in Table II., is 13.5 kilowatt hours, per ton of coal raised. Many of the pits have conditions, similar to those existing in mines in this country.

The original idea for reconstruction, was to erect one large super-power station, but, in order to minimise the disorganisation which would be created by a complete shut down, it was decided to put down a series of interlinked stations. The area is covered by a transmission " grid," carrying current at 45,000 volts and 50 cycles, which is transformed down to 3,000 volts at the collieries. The complete scheme comprises six stations each, with a generating capacity of some 60,000 kw., the stations being situated at Pont a Vendin (for the Lens area), Noeux, Courrieres, Aniche, Bruay, and Anzin. The stations at Bruay and Anzin, are fitted with pulverised fuel boilers of the Buttner and Stirling types, each having 26 boilers. The evaporation of these boilers is said to be 1 kilowatt hour for 1.01 kilogram of pulverised washery refuse.

In Germany,* where the collieries have considerable quantities of low-grade fuel, the water-tube boiler is commonly employed, especially where the steam consumption of the winders represents only a small proportion of the total steam generated, so that great flexibility of evaporation is not important. In many cases, steam accumulators are provided to supplement the boiler reserve, by supplying steam to meet peak loads. In some of the most important coalfields in Germany, there appears to be a reaction against the use of electric winders, and colliery companies which were responsible for the pioneering work in connection with electric winders, are resorting more and more to steam drive. Winders for shafts of 1,000 yards, or more in depth, are, usually, steam driven. The reason for this reversion to steam winding, is attributable to the lower cost, and, to some extent, to recent improvements in the control gear of steam winders, which makes them equal, in this respect, to the electric winding engine.

In the United States of America, the power problem appears to be similar in many respects to that presented in this country. Operators are faced with the choice between the purchase of power, or the erection of their own generating plant. In the latter case, the generating cost, per unit, is considerably lower than that at which the current can be purchased, but to this lower cost must be added, interest and depreciation on the large capital outlay required for the erection of the plant, and the attendant worries

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* Herczegh. Sheffield University Mining Magazine, 1926.

and responsibilities attending generation of current. Facilities for the purchase of current, are more common in America than in this country, with the natural consequence that a higher percentage of the power used at collieries is purchased than is the case in Great Britain.

American mines are much shallower than British mines, consequently, the winding loads are much less. Although mechanical methods of mining have progressed to a far greater extent in America, than in Britain, on account of the more favourable working conditions, yet the energy consumption, per ton raised, is less.

Some interesting details of American power schemes are contained in a recent power survey* of the Illinois coalfield. The survey covers 50 typical American mines of various sizes, and with various types of power schemes, including all steam pits, steam and electric pits, and all electric pits, both generating and purchasing power.

The average daily output of the mines, was 3,140 tons, the average depth, 401 feet, and the average thickness of the seams worked, 7 feet 4 inches. The average number of working days, per annum, was 187.5, and the energy consumption per ton raised was found to be 3.63 steam H.P. hours, or about 2.75 kilowatt hours. At only one of these pits was skip-winding adopted.

* Power Studies in Illinois. Hoskin & Fraser. University of Illinois Bulletin No. 144. Vol. XXI., No. 48. July 28th, 1924.

PART II.—PREPARATION.

Chapter 1.

CLEANING UNDERGROUND.

By W. R. Morton.

In the limited space available, it is quite impossible to consider in every aspect the problems of sorting, screening, washing, drying and briquetting coal. In fact, all that can be done is to outline the principles upon which the various processes depend and to describe and illustrate a number of units which may be regarded as typical of the machines coming under the various headings. In order to preserve a logical sequence, therefore, it is considered advisable to present the reader with an account of the various processes to which the coal may be subjected after the actual mining of the coal is complete, but before the mined product can be economically placed on the market. With this object in view, it is proposed to describe the selection of the coal underground, with the rejection of the dirt, the picking which takes place at the surface, the subsequent screening of the large and small coal and the cleaning of the coal as a whole. The latter process can be classified under two main heads, *viz.*, dry and wet processes. Whilst coal which has been cleaned by dry processes may necessitate no further treatment, washed coal requires dewatering and, for certain purposes, still further drying, whilst the slurry water, containing a large proportion of coal and dirt in suspension, requires some form of settling treatment or clarification before it can be re-used in the washery. When fine sizes of coal are cleaned on, for example, concentrating tables, the ordinary dewatering machine cannot be used to reduce the moisture content of the coal to the necessary degree, and some special form of dehydrating machine, such as a rotary or table filter, must be used if the best results are to be obtained. The ideal preparation plant is one in which screening, washing and other preparatory processes are carried out with a view to securing the maximum price per ton of output from the mine as a whole. It is desirable to aim at producing a coal of the highest degree of purity, with minimum loss of coal in the dirt or tailings, and lowest possible cost of the plant, both from the point of view of initial cost and of maintenance charges.

In the first place, therefore, it will be advisable to study the treatment that is accorded to the coal as it is freshly mined.

Cleaning underground is limited to the prevention of loading obvious impurities along with the coal. Where hand hewing is still done, this is accomplished by penalising the hewers and fillers for dirty tubs, and it is the practice to lay out and hand pick occasional tubs of coal, and if the picked out refuse exceeds a certain agreed figure, the miner is paid less than the standard rate. Even where coal cutting is done but the filling is still done by hand, this arrangement is quite workable. Where, however, the coal is conveyed off the face by machinery, as well as cut, it is practically impossible to avoid filling refuse with the coal, except for very large pieces. It is quite common now to find two coal faces loading by conveyors into a centre gate conveyor at the rate of anything up to 30 or 40 tons an hour each; and where this system of working is adopted, it is impossible to do any sorting of the coal in the face itself. In addition, many cutters either cut in a band or under or near the bottom of the coal, and even when the cuttings are separately loaded off the face, there is bound to be a certain proportion left, which is collected with the coal. Therefore, where machine mining is extensively adopted, it can be considered a certainty that the smalls will be dirtier than would be the case with hand operation. This makes it all the more necessary for a cleaning plant to be installed on the surface, though it should not be overlooked that whatever can be done in the way of preventing the loading of refuse with the coal should be done in order to save the cost of transit to the surface. The modern tendency, however, is to concentrate on getting the coal out at as cheap a rate per ton as possible, even if this involves an increase in the refuse content of the small coal sent to the surface. It is being widely recognised that if our markets are to be retained coal cleaning is a necessity in any case, and a properly designed coal cleaning plant will deal quite satisfactorily with the additional refuse involved in machine mining without adding to the capital cost of the plant or seriously decreasing its capacity.

Screening and picking.

Screening or grading of coal into different sizes is becoming increasingly important. For gas and coke manufacture the coal is ultimately used in small sizes, and the practice hitherto has been largely for the users themselves to break down the coal to the required sizes. The same thing applies to steam raising in power stations, works, etc. The only reason that buyers have preferred and paid extra for large coal, is because large coal was cleaner than small coal. If small coal could be offered with as low an ash content as large coal, it would command as good or even a better price than large coal, and it is quite possible that within a few years graded coal will almost entirely replace large coal in the markets. In the anthracite trade this, of course, is already done, with the exception of the large anthracite used for malting and hop-drying, and in the steam and bituminous classes it is quite certain that the tendency will be in the same direction, as users will prefer to have the coal delivered to them in the sizes they require, rather than to be involved in the capital expenditure and maintenance of a crushing plant. Collieries are even now making and marketing an increasing number of grades ranging from peas sized $\frac{1}{8}$in. to $\frac{1}{4}$in., up to cobbles sized 4in. to 6in. The objection to this is, that in the handling of graded coal a certain amount of degradation is caused, but the percentage of fines which the user will have to handle, due to this cause, is very much less than the percentage of fines he has to deal with now if he does his own crushing. The problem which the collieries have to solve really is, how to produce clean dry smalls, and this problem is in a fair way to being solved.

As regards hand picking, the usual plan is to put the tubs through tipplers which deliver the coal on to the main screens, these screens taking out the small, which is delivered to a separate road or to a small coal cleaning plant. Arrangements also are made whereby this can be remixed with the cleaned large coal where unscreened coal is wanted for the market, as is often the case. Where only large and smalls are made, the oversize from the main screen is delivered on to long picking belts, generally of plate construction, and the refuse is picked out by hand as the coal slowly proceeds to the end of the picking belt, where it is usual to fit a loading jib so that the coal can be delivered into the wagons with the minimum of breakage. Where cobbles and nuts are made, the main screens also make these sizes and deliver each separate size on to a separate picking belt. Frequently these cobbles and nuts picking belts are of the bar type, which permit the undersize to drop through the bars in the top strand of the belt, these undersize pieces being carried by scrapers fitted to the chains of the belt along a trough fixed under the return strands, and delivered along with the small. The size of the small coal varies in different parts of the country, ranging from 2in. to 0 to $\frac{7}{8}$in. to 0. Obviously, the more "small" that is taken out on the main screens, the better will be the results obtained on the belts, and the fewer the number of men required. It is also clear that hand picking of coal sized below 3in., such as double and single nuts, cannot be very efficient, and these are best dealt with on a small coal cleaning plant of either the wet or dry type, which will clean them more efficiently than hand picking, and a good deal more cheaply. The best way, therefore, is to confine hand picking to large coal and cobbles above, say, $3\frac{1}{2}$in. or 4in. in size, and to handle all below this in a washer or a dry cleaning plant of one of the types described below.

Chapter 2.
DRY CLEANING OF SMALL COAL.

By W. R. Morton.

In considering the question of the dry cleaning of small coal (say below 3in.) as compared with wet cleaning, it will be generally agreed that, where coal comes from the pit dry it should be cleaned dry, provided the additional price obtained for the clean dry coal brings the colliery owner a reasonable return on the capital expenditure. This, except in the cases of spiral separator plants, is generally higher than the capital required for a washery of equal capacity. Further, the cost of cleaning per ton is higher, again excepting the spiral separator, which however cannot clean below $\frac{3}{8}$in. The clean coal from dry cleaning systems, other than spiral separators, should, therefore, command a higher price than the clean wet product; and where small coal from 1in. or thereabouts to zero is concerned (in which form the vast bulk of small coal is at present sold) there are very good reasons why it should command this enhanced price.

Coal buyers are, of course, reluctant to pay more than they can help for the increased value of dry clean smalls, but they are slowly recognising that the advantages they derive by using clean dry coal are worth much more than the increase in price required by the collieries to make the cleaning plants pay.

Washed slack can seldom be reduced to below 10 to 15 per cent. moisture content, depending on the proportion of fines. The presence of this high percentage of moisture is a disadvantage in nearly all coal using processes. In steam raising this moisture has to be driven off and provided in the process with the necessary latent heat and superheat, so that every pound of water in the coal consumes approximately 1,250 B.Th.U.

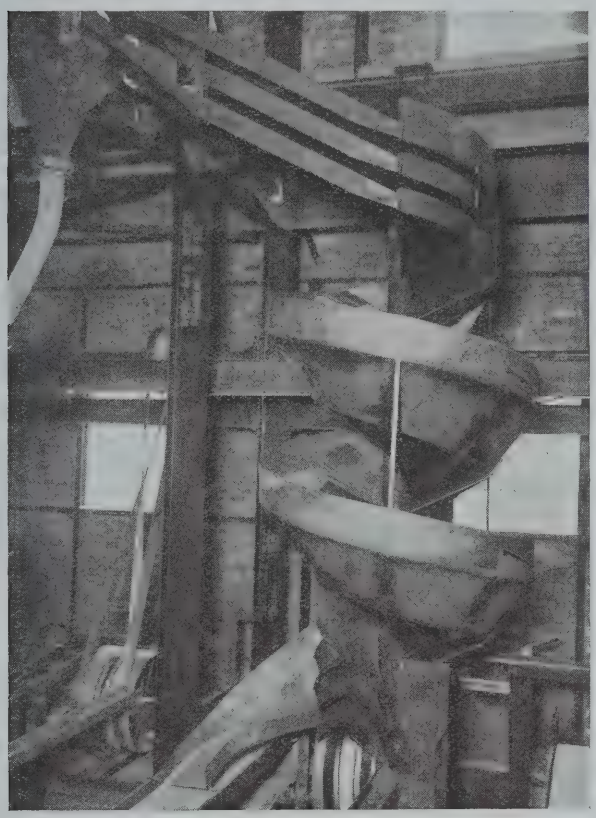


FIG. 1.—*Spiral Separator showing adjustable feed chutes, three separating threads and outer coal-collecting flange.*

For the manufacture of coke in the great majority of cases dry coal is best, as it considerably reduces the coking time required and lengthens the life of the oven walls as compared with wet coal. With some types of ovens and certain classes of coal dry coal cannot be used, but even here it is always cheaper and easier to add the required water to the dry coal than to dry down the wet coal to the required moisture figure. Similar considerations apply to the manufacture of gas.

As regards the increasing use of pulverised fuel for steam raising, dry coal is again an advantage, as the difficulty of pulverising the fuel increases considerably as the moisture content rises.

Another important point applying to any usage of coal which involves its handling is, that the wear and tear of conveyors, elevators, hoppers, chutes, etc., is less on the dry coal than on the wet coal.

Further, it has often been pointed out that large sums of money are continually wasted on the carriage of the weight of water in the washed coal, which, of course, has to be paid by the user or alternatively allowed for by the supplier. The carriage of this useless water is of no value to anybody except the carriers.

The above considerations indicate that dry cleaning is generally to the advantage of the coal user, assuming that small coal can be equally well cleaned by a dry as by a wet process. The comparative efficiencies of washing and dry cleaning depend so much on the nature of the coal and its raw refuse content, the amount and characteristics of the middlings, the use to which the coal is put and other special considerations, that it is futile to dogmatise on the subject. Generally speaking, however, there is little to choose between them in the matter of the ash content of the clean coal, when dealing with sizes down to one-eighth inch. As regards the loss of coal in the refuse, one or two modern types of washers, properly supervised, can excel anything yet achieved by dry cleaning plants, though the coal lost in the latter is almost negligible, and certainly is less than the loss in a great many washers now operating. With regard to coal below $\frac{1}{8}$in. the best results, from the standpoint of ash content reduction, have been obtained on wet concentrator tables and by the froth flotation system; but both these systems involve a very high moisture content; so that from the buyer's point of view, their product is often not so valuable as a dry product with somewhat higher ash and much lower moisture.

Another consideration which must be taken into account is that the dry cleaning of small coal involves the handling of large quantities of dust, which must be collected. Up to now this has been a somewhat costly business, though great improvements have recently taken place whereby excellent dust

collection can be achieved with a much lower power expenditure. Dust so collected can, if required, be mixed with the clean slack; it can be made into briquettes sufficiently robust to be handled and burnt in the colliery boilers; or it can be burnt under the boilers as pulverised fuel; as appliances are now available for burning it in Lancashire boilers.

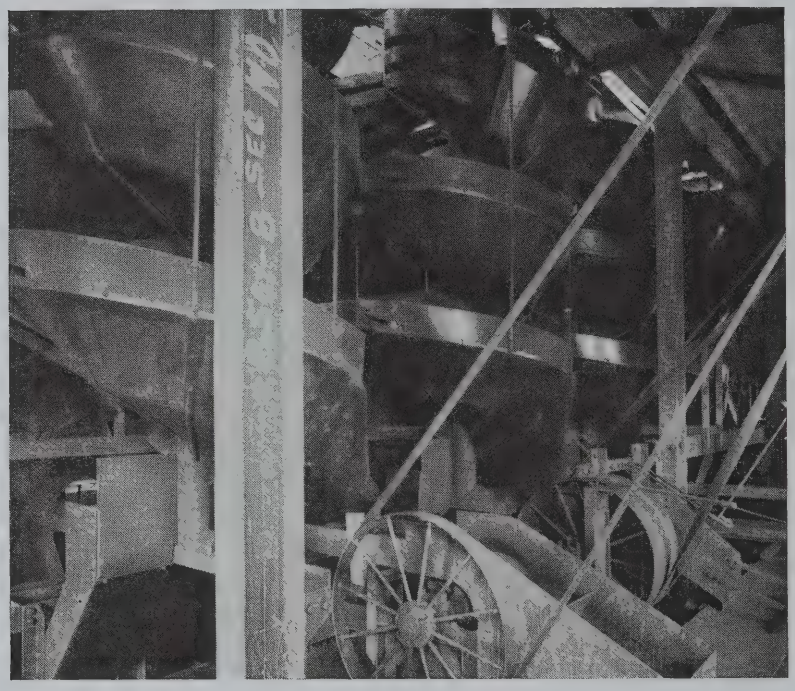


FIG. 2.—*Spiral Separator installation at a Northumberland Colliery. Capacity 50 tons per hour.*

Comparable to the dust production of dry cleaning plants, is the slurry production of washers. Dust is hard and costly to collect, but comparatively cheap to dispose of economically. Slurry is easy and cheap to collect, but extremely difficult to dispose of economically. They may be allowed to cancel out, with a slight and probably increasing advantage on the side of the dust.

The choice between a wet and dry cleaning process will ultimately be decided by the coal user. Therefore, the colliery owner intending to instal a cleaning plant must first consider (1) the special needs of the consuming process to which his coal is most suited; (2) which system, wet or dry, will most fully meet those needs, bearing in mind the special characteristics of his coal. There is ample scope for both systems of cleaning, though probably dry cleaning has the better prospects.

SPIRAL SEPARATORS.

Spiral separators are suitable for cleaning all anthracite coal and most bituminous coal, though in both cases the coal must be dry when delivered to the separators.

They are mainly used for coal between 4in. and $\frac{3}{8}$in. in size, and will not separate coal below $\frac{3}{8}$in. They may be used on coal larger than 4in., though this is as a rule better dealt with on hand picking belts.

There are many spiral separator plants in continuous operation in this country, and they include over two hundred spiral separators. They are dealing with over two and a half million tons of coal per annum, which is a greater quantity than is being dealt with by any other system of mechanical dry coal cleaning, and their use is rapidly extending. They clean the coal so that not more than two per cent. of free refuse remains in the cleaned coal and not more than one-quarter of one per cent. of the coal treated

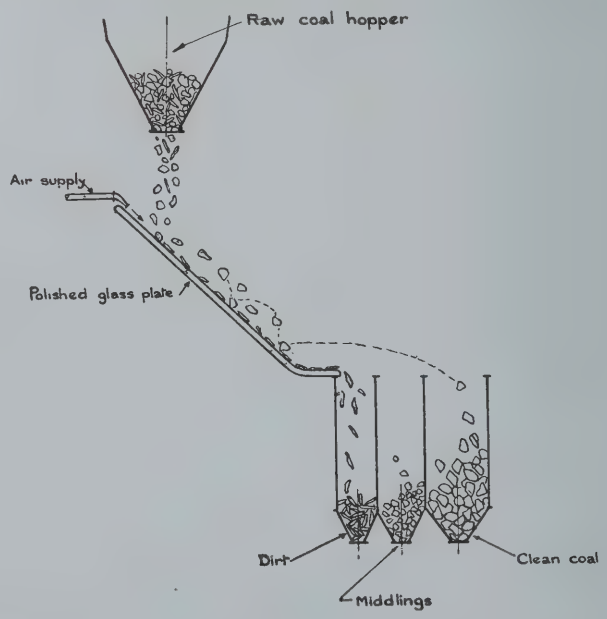


FIG. 3.—*Diagram shewing principle of Berrisford Separator.*

is lost in the stone end. A spiral separator plant possesses one unique advantage, in that after stoppage it can be restarted at full efficiency without any adjustments or taking any precautions whatever. All other types of cleaning plant on stopping and starting involve a more or less lengthy period of adjustment before working normally again. Spiral separators are very cheap to operate, the total cost, including wages, power, supervision, maintenance, interest on capital and depreciation, being about fourpence per ton of coal cleaned.

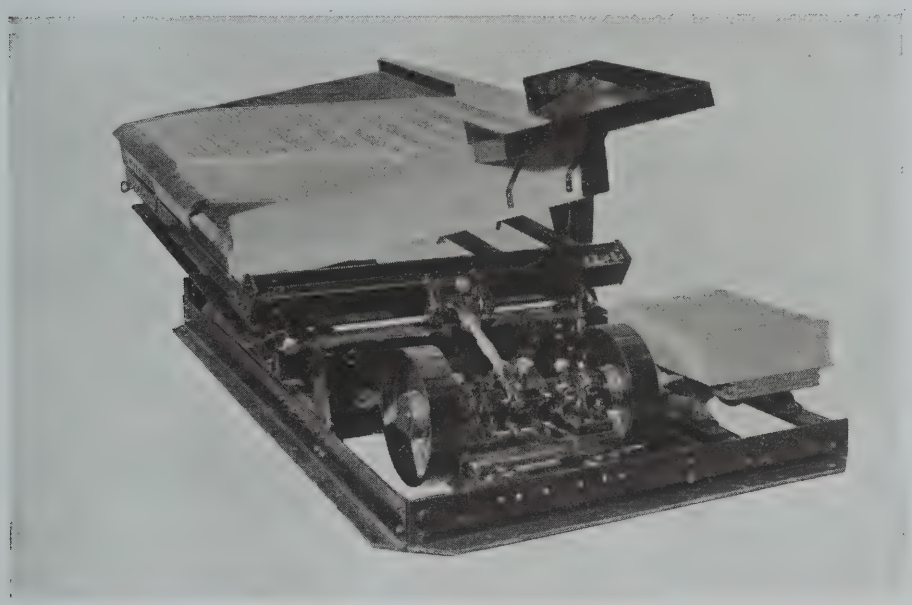


FIG. 4.—*The "Arms" Air-cleaning Table.*

Quite apart from the low cost of treatment and the good results obtained, the installation of a spiral separator plant at a colliery enables the larger coal to be better cleaned, due to the absence of all material below 4in. on the belts, and enables this better cleaning to be accomplished by half the men who previously were employed, so that the cost of operation is always more than balanced by the labour saving effected on the picking belts.

Spiral separators are stationary and the principle on which they operate is to take advantage of the difference between the coefficients of friction of coal and refuse when sliding on steel plates. The raw coal is fed on to the feed chutes of the spiral separators and slides down the three separating threads which are fixed spirally round a central post, and which are designed with the correct pitch and form to allow the coal to attain sufficient speed before reaching the end of the separating threads to leave them and fall off the edge into an outer coal-collecting thread. The higher coefficient of friction of the refuse prevents this material attaining the requisite speed to clear the edge of the threads, so that it is retained on them and delivered separately at the bottom of the separator. In addition to retaining the actual refuse, or stone, these threads also retain the middlings in the coal. These middlings, or intermediates, generally consist partly of coal with a comparatively low coefficient of friction and which generally has also a high ash content; partly of intergrown coal and stone; the remainder consisting of refuse with a comparatively high coefficient of friction, and which as a rule has a low ash content compared with the rest of the refuse. The free refuse hugs the central post closely, but these intermediates take up a position towards the top of the slope of the separating threads and near the edge, so that they also can be separately collected. Alternatively they can be delivered either with the coal or the stone at will by means of a simple adjustment at the foot of the spiral. Fig. 1 shows a spiral separator. The adjustable feed chutes, the three separating threads, the outer coal-collecting flange; the wing adjustments at the bottom of the separating threads and the levers for adjusting the effective widths of the jackets can all be seen.

In designing spiral separator plants careful attention must be given to a number of points, which are briefly as follow :—

Spiral separators must not be overloaded, as if they are, separation ceases, so that the number of spirals in a plant should be selected so that the rate of feed never exceeds the capacity of the spirals. With coal sized above 1in. each spiral will do 7 or 8 tons per hour if the amount of refuse in the material does not exceed 15 per cent. Where this percentage is exceeded the capacity falls in proportion. For coal

sized under 1in. each spiral will do 5 to 6 tons per hour, again assuming a refuse percentage of 15 per cent. with a corresponding fall in capacity for higher percentages.

To ensure that overloading is impossible it is necessary that the feed to the plant should be absolutely regular, and for this purpose it is necessary always to instal an adequate storage hopper which will take care of the fluctuation in the quantity coming from the pit. The discharge from this hopper should be preferably in the form of a jigger, which may form a portion of the main screen, and which takes a definite quantity of coal at each stroke.

Accurate sizing in ranges which are not too great is necessary on spiral separator plants, and each size must be treated on its own separators. No grade should contain more than 5 per cent. oversize or undersize, and the screens must therefore be very efficient. They should be of the high speed low pitch type, with screening areas very much greater than has been the practice in the past. This accurate screening is really an advantage to the operator of the spiral plant. The sizes can easily be arranged to suit the market, so that the colliery is able to offer accurately graded coal as well as clean coal, and this is now, in many markets, a great advantage. The ranges generally used in dealing with 4in. by $\frac{3}{8}$in. coal are:— 4in. to $2\frac{1}{2}$in.; $2\frac{1}{2}$in. to $1\frac{1}{2}$in.; $1\frac{1}{2}$in. to $\frac{3}{4}$in.; $\frac{3}{4}$in. to $\frac{3}{8}$in. These ranges can be lengthened and shortened within reason to accommodate market requirements.

The intermediates must always be collected separately. Local conditions will decide what is the best way to deal with these intermediates. Where the market permits, the best of them can be delivered along with the clean coal. Alternatively they may be taken right out of the plant and burnt under the colliery boilers on one of the many excellent arrangements now available for burning splint coal. Where a separate plant is installed for cleaning the material below $\frac{3}{8}$in. in size, they may be crushed down to this size and sent to this plant for treatment. Where this is not the case, they can be crushed to the smallest size which the spiral separators are dealing with and recirculated through the plant. This crushing will largely free the intergrown coal from the adherent stone and a large portion of this coal will be recovered.

Where the coal is very dusty, it is necessary to instal a dust collecting plant, as if the separating threads on the spirals get thickly coated with dust, separation is impeded. The dust thus collected is admirably suited for use as powdered fuel without further pulverising, or alternatively can be made into briquettes, which can be used for firing ordinary Lancashire boilers.

The travelling speed of the coal on spiral separators is affected by the condition of the atmosphere, so that they must always be erected in well-covered buildings. In warm dry weather the speed of the coal decreases, and it is necessary to fit a water spray, or atomiser, whereby the coal is slightly damped as it passes over the grading screens in order to maintain the correct speed on the spirals themselves.

Assuming that the above points have been cared for, there is no difficulty in obtaining, and maintaining, good results, where an intelligent supervisor is employed. One man can easily look after twenty spirals, provided he is alert and intelligent, and a comparatively short period of training is all that is required. Some collieries operating spiral separator plants give a bonus to the separator foreman, based on the results which he obtains from the plant, and this method has proved to be an excellent one. It may cost the colliery an additional £1 per week, but it will probably result in a 3 or 4 per cent. reduction in the ash content of anything up to 3,000 tons of coal a week.

Means are provided on spiral separators for making various adjustments (see Fig. 1). The three feed chutes, which are arranged to divide the total feed equally, are adjustable as to slope. The coal should enter these feed chutes with a minimum velocity, and for this reason a jigger feeder is usually employed. Some coals are faster than others and require a less slope, in order to enter the separator at the correct velocity and the correct slope for any particular coal is easily found.

The jackets of the separating threads themselves are arranged so that every alternate section has an adjustable edge formed of a perforated friction plate. These plates can be thrown in or out so that the amount of friction and the effective width of the jackets can be varied at will. These movable wings can be of plain unperforated steel if desirable; and in addition, the solid immovable jackets can, if required, be fitted with friction plates so that any combination of friction and jacket width can be obtained.

At the bottom of the separating threads adjustable dividing wings are provided, whereby the whole or a portion of the middlings may be diverted to the coal end or the stone end, according to what sort of separation is required. Once the right adjustment is obtained, very little alteration is needed to take care of the slight changes in the speed of the coal caused by atmospheric conditions.

Fig. 2 shows the interior of a Northumberland spiral separator plant. This plant has a throughput of 50 tons per hour and makes trebles (3in. by 1½in.) doubles (1½in. by ⅞in.) and singles (⅞in. by ⅜in.), each of which and the uncleaned duff below ⅜in. can be delivered into a separate road. Provision is also made for delivering the cleaned singles with the uncleaned duff to make a clean rough small. Also all the cleaned coal can be delivered on to a mixing conveyor and thence to the main picking belts, where it is mixed with the hand-picked large to make a clean unscreened. This plant is typical of many similar plants, most of which are arranged both for making separate grades and remixing.

The Berrisford Separator. In the Berrisford separator (Fig. 3), although the raw coal slides down an inclined surface, the coefficients of sliding friction of coal and refuse have no appreciable effect on the separation. The special feature of this machine is that it is designed to utilise the difference in resiliency of coal and stone, which it is considered gives as wide a margin for separation as for sliding friction. The apparatus used to employ this difference of resiliency consists of a sloping glass plate on to which the coal is bounced, and this bounce, it is claimed, provides the necessary difference in velocity between the coal and the refuse. The lower edge of the glass plate is bent to form a lip which is practically horizontal, this having been found necessary in order to quench the second bounce of the coal, and prevent it accidentally dropping through the dirt gap which follows the lower edge of the glass plate. Although this horizontal lip of the glass plate eliminates the second or third bounces of the coal, it does not interfere with the relative velocity at which the coal and refuse pass over the edge of the glass plate, so that the particles of coal leave this edge at a higher velocity than the particles of refuse, and are enabled to jump over the dirt gap on to a receiving clean coal plate or chute, whereas the velocity of the refuse is too low to permit it jumping the gap and it falls through. A gentle air blast is provided for the purpose of keeping the glass plate free from dust, which if allowed to settle, would impede separation.

The dirt gap is divided into two portions. The first portion next to the glass plate receives the heaviest and slowest of the refuse, which is practically pure stone. The second half of the gap receives the middlings, which are a mixture of coal and the lighter end of the stone. These middlings are discharged on to a second separating plane, the function of which is to remove the pure coal from the middlings.

These machines have been installed in several collieries in the Midlands for dealing with 2in. nuts, and also coal sized between 1¼in. and ⅜in., and the results obtained at these collieries have been satisfactory.

The Berrisford separator is belt driven, and can be installed in existing screens with very little alteration. The capacity is given as about 15 tons per hour on 2in. nuts, with correspondingly smaller capacities on smaller material. The space required to accommodate one of these machines, apart from the feeding and delivery arrangements, is about 7 cubic feet.

PNEUMATIC SEPARATION.

Considerable progress has been made with this system of dry cleaning small coal in the last few years. The separation is made chiefly by reason of the difference in specific gravity between the refuse and the coal, as is the case in wet washing plants. The essential feature of pneumatic separation is the agitation of a bed of raw coal in an upward current of air. The bed of coal is fed on to a jigging table which is provided with a perforated inclined deck, and a current of air at a suitable pressure is blown through this bed of coal which stratifies it, lifting the lighter coal to the top and allowing the heavier refuse to accumulate at the bottom of the bed. The table deck is provided with longitudinal riffles, and these serve to retain the refuse at the bottom of the bed. The lighter coal is lifted clear of the riffles and travels down the slope towards the front edge of the table at right angles to the longitudinal centre line. The jig of the table traverses the refuse in the riffles to the end of the table, where it is separately collected. Between the refuse and the clean coal is an intermediate, or middlings, which is also separately collected, and these middlings are usually recirculated through the plant, though they can, of course, be separately

disposed of, if desired. By means of such tables, coal below 2in. or 3in. and right down to zero can be successfully cleaned. There are a large number of plants operating in America which are dealing with somewhere about ten million tons of coal per annum, and new plants are being rapidly installed, some of these plants dealing with as much as 400 tons per hour. A number of such plants have also been erected in this country, and it is anticipated that shortly a quantity approaching two million tons per annum will be cleaned on pneumatic separators.

In order to achieve satisfactory pneumatic separation a certain amount of sizing is essential; i.e., the ratio of the size of the largest particle fed to a table to the size of the smallest particle must not exceed some definite figure. Various attempts have been made to define the value of this ratio mathematically, based on formulae, which assume a relation between the ratio of the different specific gravities of the coal, the refuse and the separating medium. The ratio figures obtained by these formulae do not square with the results obtained in practice, which are even now much better than are theoretically possible. There are other variables besides specific gravity to be considered, e.g., the infinitely varying shapes of both coal and refuse, so that such formulae are practically useless, except to demonstrate that there must be *some* limit to the range of size which can be treated on one table. Further the ratio will vary with different coals. The highest theoretical ratio permissible is 2 to 1; whereas efficient separation is being effected with a sizing ratio varying between this figure and 4 to 1, depending on the relative weights and shapes of both coal and refuse particle. The best sizing ratio for any particular coal can only be ascertained by actual trial.

This necessity for grading the coal to be cleaned (generally 2, 1½ or 1in. to zero) into separate sizes, each of which must be treated on a separate table, is not necessarily a disadvantage provided there are not too many sizes. As already pointed out, the tendency is more and more for collieries to make separate grades for the market, so that as time goes on this may become a necessity, not because it is required for efficient cleaning, but because the markets demand it. Most of the modifications recently made in the design of pneumatic cleaning tables, therefore, have aimed at reducing the number of sizes to probable market requirements and increasing the capacity per table, thus reducing the capital cost per ton treated.

It is an easy matter on almost any pneumatic separator to remove the coarser refuse from a long range of size without losing any coal. Generally speaking, however, in this country the bulk of the objectionable refuse in the smalls is found in the finest fraction of the coal, and if the value of the smalls generally is to be sufficiently increased to command so much better a price as will justify the installation of a cleaning plant, then the smallest sizes must be adequately cleaned, and this involves a certain amount of sizing.

The best known types of pneumatic coal separators are the "Arms" separators and the Sutton Steele separators, with their subsequent development, the "Wye" tables.

"*Arms*" *Air Cleaning Table.*—The "Arms" air cleaning table (see Fig. 4) consists essentially of a jigging table deck, generally with a perforated wire mesh top on which are mounted riffles of special design running approximately in the direction of the movement of the table, though not always parallel to it. This perforated deck is flexibly connected to an air cone mounted underneath the table on the discharge of a blowing fan which forces air through the deck mesh at the required pressure. The deck itself is mounted in a steel deck frame supported on rockers, mounted in a steel slope frame adjustable on both diameters. The whole is mounted on a steel base on which is fixed the crank shaft and fly wheels, driven through a variable speed gear having a range of 50 per cent. either side of normal, which is about 300 r.p.m. The table requires only 1 or 2 H.P. to operate. The coal is fed at one of the back corners of the deck. The refuse is delivered at the diagonally opposite corner, the coal along the front edge and the middlings also at the front but close to the refuse delivery.

The total quantity of air supplied can be varied by a butterfly valve in the fan inlet; the quantity supplied to any part of the deck can also be varied by special baffles and perforated air resistance plates in the underframe. The slope from back to front of the table can be varied as required by the proportion of refuse in the raw coal, and also the slope from end to end. In addition the number of strokes per minute can be varied within wide limits. Most of these adjustments can be made with the table running so that it is easy to achieve a good separation quickly, which will maintain itself provided there is no wide variation in the proportion or character of the refuse. Separate chutes for receiving the cleaned coal,

the middlings and the refuse are provided, and these are so arranged that the width of the middlings taken can be immediately varied as required. There are thus a large number of adjustments which can be made. It is therefore easy to obtain the kind of separation required, which, of course, depends largely on the characteristics of the coal being treated, and on the requirements of the market. Where there is a lot of middlings between 1.400 and 1.600 S.G. it is generally impossible to discard these, as it would involve the loss of a very large amount of valuable combustible material and of too high a proportion of the total coal. In such cases the aim of the operator would be to get within a reasonable distance of the ash content of that portion of the coal which floats in, say, 1.500, so that the better fraction of the middlings would be saved without causing the total ash content to be too high. In other coals there may be little intermediate, in which case a reasonably good separation can be effected with the loss of practically no combustible material in the stone. The latest modifications in this " Arms " table have been in the direction

FIG. 5.—*" Arms " Table installation cleaning coal of ¾in.-⅜in. size.*

FIG. 6.—*Installation of Birtley Tables, showing Separator floor.*

of increasing the range of size which can be treated, and it has been found possible to make really good cleanings at ranges of 3 to 1, and even in some cases of 4 to 1.

The capacities obtained per table range from 35 tons per hour on coal sized from 3in. to ¾in. down to 10 tons per hour on coal below ⅛in. The capital cost of a complete installation is between £15 and £20 per ton per hour of coal treated, and the cost of cleaning including repairs, maintenance, power, labour, interest on capital and depreciation, etc., is between 5½d. and 7d. per ton, of which about one half is accounted for by capital charges. The ash content of the clean coal down to ⅛in. or 1/16in. is within 2 per cent. of the ash content of the fraction of the raw coal floating in 1.500 and the coal in the refuse does not exceed 2 per cent. of the weight of the refuse. Below ⅛in. or 1/16in. the cleaning is less efficient, as in spite of the fact that the dust collecting plant removes the finest of the raw coal, the ratio between the largest particles and the smallest particles is too great, and screening below 1/16in. is not a commercial proposition.

Fig. 5 illustrates a plant in Northumberland which is cleaning ¾in. to ⅛in. coal, making beans and peas, the duff below ⅛in. being by-passed uncleaned. The cleaned beans and peas regularly give an ash content of 7 per cent. and 8 per cent. respectively, the raw coal ash content varying between 17 per cent. and 28 per cent. The average ash content of the 1.500 floats in the beans and peas is 5 per cent. and 6 per cent. There are an increasing number of " Arms " cleaning plants operating in U.S.A. and Canada, dealing with quantities up to 400 tons per hour and with coal between 4in. and zero.

The Sutton Steele Separator.—The Sutton Steele, type " SJ," separator was the first commercially successful air cleaning table. It operates on the principle of a mechanically agitated bed of coal subject to a continuous upward current of air, as does the " Arms " table which followed it. The controls and adjustments available are generally similar to those already described in connection with the " Arms "

table, though the means used to obtain them are different. The distinctive feature of this table is the provision of a banking bar along the refuse end of the table, against which the refuse is piled; this bank of refuse offers a surface at a steep angle to invading particles of coal or middlings and repulses them back on to the flat deck, so that the refuse is automatically kept pure. In addition, the refuse bank is stratified by the air passing through it, so that the smaller particles of refuse are enclosed, and overlaid by the larger, thus ensuring that they are not lifted back into the coal or middlings by the air current. This enables the table to achieve and maintain a refuse end practically free from coal with very little alteration once the right degree of banking has been secured. The results obtained by these separators are very good on coal down to $\frac{1}{16}$in. in size, the clean coal regularly showing within 2 per cent. of ash in the 1.500 S.G. floats, whilst the coal in the refuse is always below 2 per cent. of the weight of the refuse and frequently averages 1 to 1.5 per cent. A plant in County Durham embodying these separators and treating 120 tons per hour has been in regular operation since the 1926 coal strike. The size of the coal treated is 2in. to $\frac{1}{16}$in., the minus $\frac{1}{16}$ being by-passed. The plant was installed to enable the coal company to guarantee that the ash content of the whole of the gas coal shipments, which include the uncleaned

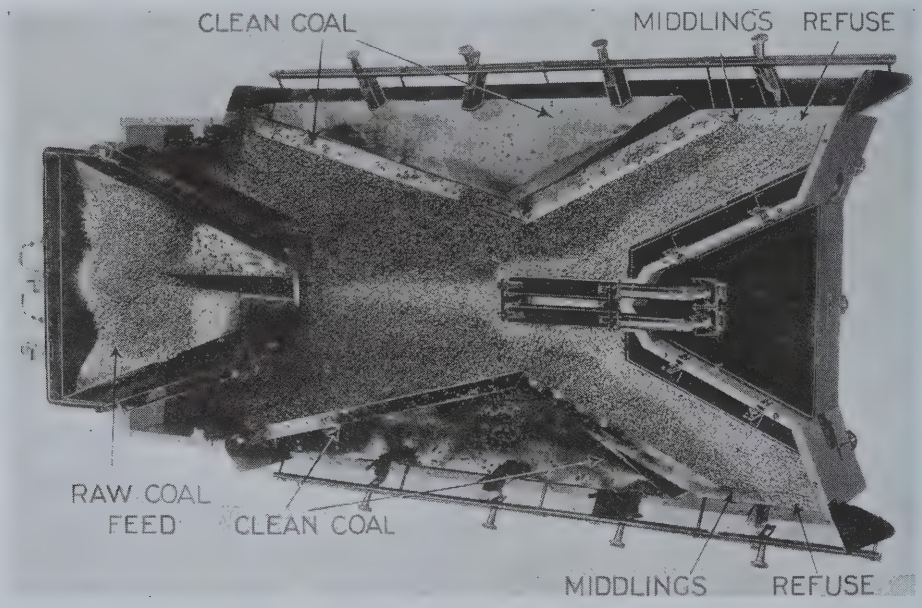


FIG. 7.—*The Birtley "Wye" type Separator.*

minus $\frac{1}{16}$in., should always be below 8 per cent.; and this is regularly achieved. The sizes treated on separate tables are 2in. by 1in., 1in. by $\frac{1}{2}$in., $\frac{1}{2}$in. by $\frac{1}{4}$in., $\frac{1}{4}$in. by $\frac{1}{8}$in., $\frac{1}{8}$in. by $\frac{1}{16}$in. (two tables), a total of six separators.

Fig. 6 shows a view of the separator floor. The ratio of size used is 2 to 1, beyond which ratio these separators do not give such good results. The designers have now developed a new separator retaining some of the features of the "SJ" type, but giving larger capacities and permitting longer ranges. This is the "Wye" separator.

The "Wye" Separator.—The "Wye" separator in plan takes roughly the shape of a Y and is illustrated in Fig. 7, which shows the feed and the clean coal, middlings and refuse deliveries. It is symmetrical about the longitudinal centre line, and the surface slopes down from the centre line to the long edge, so that on a full "Wye" table this slope is fixed, and has to be determined by preliminary test on the coal to be treated.

End slope can be varied and all the other adjustments available on the "SJ" type are also provided. The coal is fed on to the tail of the Y. The riffles on this portion of the deck run parallel to the centre line of the table. The riffles on the two arms of the Y are parallel to the long centre line; and the coal delivery line, over which the last portion of clean coal is delivered, diverges from the centre line. The process of

separation is different from that of " SJ " separators. It takes place in two stages, the first on the tail of the Y and the last on the two arms. The coal is stratified on the tail and the bulk of the clean coal is discarded. The refuse is concentrated about the centre line by the converging riffles; and here also the smaller refuse particles are concentrated in a zone of low air velocity which prevents them being lifted over into the clean coal. It is this last feature of the Y table which permits of the use of larger ratios of sizing than are possible with the " SJ " type. The stone is traversed along the centre of the tail and then split and banked up against the two banking bars which form the inside edges of the two arms.

A half " Wye " separator is obtained by splitting a full " Wye " longitudinally. It consists of half the tail and one arm, and is used for lower capacities. This type has the advantage of permitting a slope adjustment from back to front, which cannot be obtained in the full " Wye."

On the " Wye " tables sizing ratios of 4 to 1 can be used and the same cleaning efficiency achieved as on the " SJ " tables, so that they offer considerable commercial advantages over the latter, as the number of screening steps required is halved. The capacity of the full " Wye " also is, roughly, double that of the " SJ," so that in plants dealing with large throughputs the number of separators required is reduced by half. The capacities are as follow:—

Size.	Full " Wye."	Half " Wye."
2in. by ½in.	60/70 tons per hour.	30/35 tons per hour.
½in. by ⅛in.	30/40 „ „	15/20 „ „
⅛in. by 0in.	20/25 „ „	10/13 „ „

Typical results show a clean coal on size down to ⅛in. with an ash content of less than 2 per cent. above that of the 1.5 S.G. floats. On the ⅛in. to 0in. the results are not so good, due to the sizing ratio being too great. This with the finest material removed by the dust plant is 8 or 10 to 1; but despite this excessive range, the total ash content of the ⅛in. to 0in. is generally reduced by more than half.

A number of " Wye " table plants are at work in U.S.A. and several plants embodying the " Wye " and Half-Wye separators are now being installed in this country.

Chapter 3.

THE WET CLEANING OF COAL.

By ARTHUR GROUNDS, B.Sc., A.I.C., A.M.I. MIN. E.

In order to understand the principles upon which wet cleaning methods operate, it is necessary to know what impurities are likely to occur in coal and what are their physical characteristics. The impurities occurring in coal consist largely of inorganic (i.e., mineral) substances, some of which formed an inherent part of the original plants from which the coal has been produced through the ages, whilst others may be regarded as adventitious matter which has percolated into the coal seams either by the action of constant streams of water or by other physical agencies. Still further quantities of foreign matter are introduced during mining operations by the inclusion of portions of the roof or floor of the seam, the latter impurity consisting generally of shale or fireclay-like material. Of the other impurities, pyrites is probably the densest, this substance having a specific gravity of 3.0 to 5.0 according to its physical nature. It can be recognised by its golden lustre, and in fact is known in some localities as " fool's gold." It may generally be easily separated from coal because of the wide difference in specific gravity between pyrites and coal. Another impurity, found especially in bituminous coals, is the material known as ankerite. This is a combination of the carbonates of calcium, magnesium, iron, manganese and possibly other elements. The specific gravity of ankerite varies from 2.5 to 2.7, and it may be readily recognised since it forms the white " partings " which occur like thin sheets of marble usually in a vertical plane in the coal seam. " Bone " coal is also liable to occur in a number of seams, and consists of a dull variety of coal of high ash content. In some seams, however, notably the Arley and Trencherbone seams of Lancashire, bone coal may actually contain less ash than the associated coal. The specific gravity of coal itself is usually of the order of 1.2 to 1.45, and separation methods nearly always depend upon the difference in specific gravity between the coal and its impurity.

In choosing the layout of a cleaning plant, it should be borne in mind that every seam must be treated according to its characteristics, and what may prove to be an extremely effective plant at one mine, may not produce the desired results if copied in every detail at another mine. Experts still disagree as to whether or not it is advisable to screen before or after washing, yet it seems certain that the jigging of bituminous coal can be carried out with entire success without preparatory sizing. The advisability of pre-sizing before washing should, however, be considered separately for each installation. Prochaska claims that to produce a perfectly sized coal (washed), screening *after* washing is essential. Wet washing of coal has followed in the footsteps of the wet treatment of ores in metallurgical practice, for the concentration of the ore and the rejection of the gangue. The most common type of washer is based on the principle of the jig. This is usually built in the form of a tank, divided by a vertical partition into two compartments. The partition does not reach to the bottom of the tank, so that the compartments are in communication. In one compartment is mounted a plunger, actuated by mechanical means, whilst in the other cell is a screen, mounted either horizontally or in a slightly sloping position. This screen, together with its superimposed load of raw coal and dirt, is always submerged, so that on the down stroke of the plunger the water in the plunger compartment is forced up through the perforations in the screen, thus tending to lift the layer on the screen. On the up stroke of the plunger, the water recedes and the layer is allowed to fall back on the screen. This continual jigging motion leads to stratification of the layer, the shale and pyrites tending to rest on the screen, whilst the coal rises to the top of the layer. Space does not allow of a consideration of the theories of free and hindered settling, but it may be taken that under hindered settling conditions, washing 3-in. screenings, slate as fine as ¼in. can be removed from the coal, whilst if we wash 1-in. screenings all impurities larger than 10 mesh will pass into the refuse. The jig type of machine is probably best illustrated by the British Baum coal washer as manufactured and built in this country by Simon-Carves, Ltd. This is illustrated in Fig. 1, which shows a diagrammatic arrangement, from which the operation of the machine will be easily followed. The Coppee washer also functions on this principle. In the Baum washer, in place of a mechanically-operated piston, the reciprocating motion of the water column is produced by the periodic application of compressed air on the water surface. The dirt falls on to the screen and is removed, whilst the coal rises to the top of the layer and is carried forward over the lip of the discharge into a separate receptacle. By using a series of jigs, a gradual reduction in the proportion of dirt is effected until the necessary degree of cleaning has been produced. The treatment of the wet coal is described later.

It is claimed that owing to the effectiveness of the separation, it is possible to wash slack below 5-inch mesh without initial classification into various sizes, thus eliminating dry screens. The great advantage of screening after washing is the reduction which can be made in the sizes of the various screens required, since all the dirt has been already removed. Contrary to the older type of washer, felspar beds are not required, the necessary bed being provided continuously by the dirt extracted from the raw slack. The lighter products from the first section of the box are again treated in the second section, in which the last traces of dirt are extracted. The large dirt is collected along with the fine dirt in each section by one individual elevator, the larger dirt acting as a filter bed for the smaller stuff. Thus all the dirt is dealt with by means of elevators in which draining takes place, and it can therefore be disposed of without further handling. The boxes themselves are constructed deep enough to allow the small dirt to settle without the possibility of its being carried away with the current of water and mixed with the coal. The wash water is usually dealt with in the Baum washer by means of a special conical tank, in which the velocity of the water is progressively reduced, so that the solid matter settles out smoothly, being discharged through a special valve and re-introduced to the washery to be mixed with the fine coal. Feed water is introduced as required for make-up purposes, whilst the clear water is withdrawn from the periphery of the tank at the top. A separate pipe introduces water into the slurry discharge pipe in order to regulate the consistency of the slurry. The washed coal is then drained by being slowly elevated in elevators provided with perforated buckets, or by gravity feed from the screens direct or by conveyance over shaking screens. The slurry recovered from the settling tank is also delivered on to the shaker screens along with the fine coal, thus being both drained and intimately and uniformly mixed with the fine coal. If further dehydration be desirable, the coal must be passed into storage and drainage bunkers, where it can be left

undisturbed for the requisite drainage period. A single box of 20 feet length and 12 feet width will deal with up to 130 tons per hour of coal from 4 inches to 0 with a 2 per cent. margin of error each way, i.e., coal in the dirt or *vice versa*.

The trough type of washer is best exemplified by the Notanos washer, manufactured by Head, Wrightson and Company, Ltd., of Stockton-on-Tees, and illustrated in Fig. 2. It will be seen that the raw coal is delivered from the feed hopper on to the feed tray, on which it is conveyed forward, so that distributed uniform quantities fall with each stroke into the washer box. This box has a riffled bottom, sloping upwards from the gear end of the machine towards the shale discharge end of the trough. On the base of this trough, the material meets a stream of water flowing down the incline from the water feed pipes. The continuous jigging and the flotation action of the water bath in the lower end of the trough lead to segregation of the coal and shale, the coal being floated over the adjustable sill to the lower deck. On this, the washed coal is propelled forward up a slight incline over the wedge wire draining trays, on which the moisture content is reduced. The dewatered coal is delivered to storage bins, whilst the drainage water and slurry are fed through the drain box and launder to the sump of the washery pump. Again, an overhead conical settling tank is used for the separation of the fine coal from the water, so that the washery can be supplied with clear water for washing purposes. The shale settles on the floor of the washing trough or box, and is conveyed forward up the sloping base of the box to the upper end against the current of water by the jigging motion

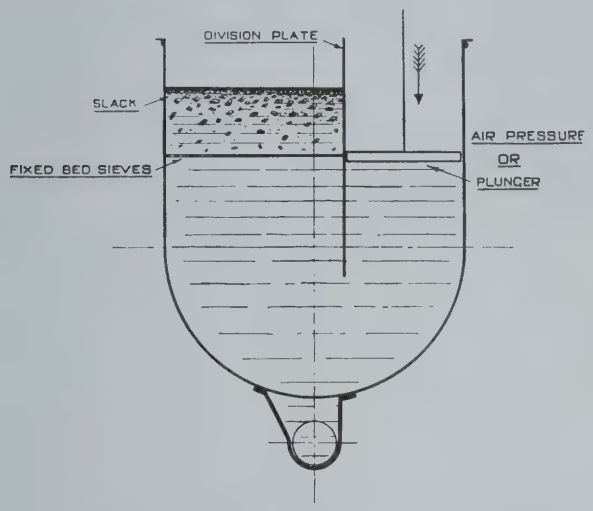


FIG. 1.—*Sketch shewing principle of Baum or Jig Washer.*

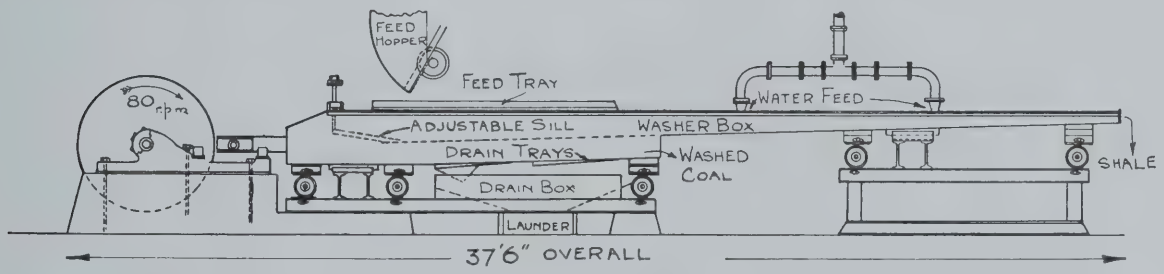


FIG. 2.—*Notanos Washer.*

imparted to the box, being discharged to a conveyor for removal to the waste dump. The following details will give some idea of the capacity of the plant in its various sizes:—

Width of Washer.	H.P. absorbed.	Capacity, tons per hour.	Water, galls. per min.	
			Circulation.	Make-up.
4ft.	7.5	10	200	2.67
5ft.	9.0	15	290	4.0
6ft.	12.5	20	380	5.3
7ft.	15.5	25	470	6.7

For finer or coarser coals, the above figures may be decreased or increased by about 20 per cent.

The Blackett washer also operates upon somewhat the same principle, in that it consists of a revolving drum into which the raw coal is fed. The axis of the drum is slightly inclined and the drum is provided inside with spiral guides. Water is fed down the drum and washes the coal downwards and through the lower end of the drum, whilst the shale is of sufficiently high specific gravity to cling to the surface of the drum, being conveyed towards the upper end of the drum where it is discharged into the shale conveyor.

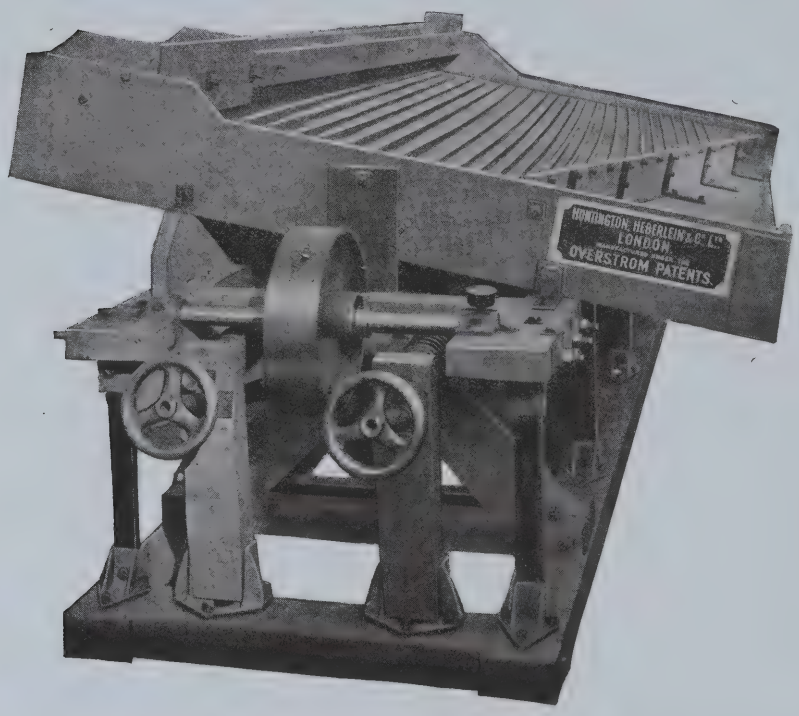


FIG. 3.—*H.H. Universal Curvilinear Concentrator for washing Small Coal.*

The trough washers just described are both moving washers, but in the simple trough washer a fixed trough is used. This is inclined at a slope of about 1 in 12 to the horizontal, and may be from 40 to 100 feet long, about 3 feet wide and about 18 inches deep. The velocity of the current of water is such that it carries forward the coal, the heavier shale being deposited on the floor of the trough, where it is retained by barriers or weirs and is run off at intervals through a shale sluice after removal of the weirs. In the Elliott washer, a scraper conveyor is used in place of the movable dam, the slope of the trough being capable of modification, so that the washing operation is under better control than in the simple trough.

The separation obtained in these washers is far from perfect, and fine coal, in particular, cannot be treated at all satisfactorily.

Another unit which utilises the flow of water down an inclined plane is the concentrating table, illustrated in Fig. 3. The raw coal is fed on to the upper edge of the table, which is given a transverse jigging motion. Water is fed on to the table with the coal and the whole of the coal and shale commences to travel downwards over the table deck. Riffles are mounted transversely on the table deck, however, and the current of water is so adjusted that whilst the coal is floated over the riffles, the heavier shale settles out in the channels between the riffles and is conveyed by the jigging motion to the shale discharge end of the table, whilst the coal is washed over the lower edge. These tables give excellent results on the smaller sizes of coal and are capable of treating coal down to one sixteenth of an inch size with a separation within one per cent. of that attainable by a float-and-sink test. The capacity of a standard table of the H.H. Overstrom type, such as is illustrated in Fig. 3, varies between 5 and 12 tons per

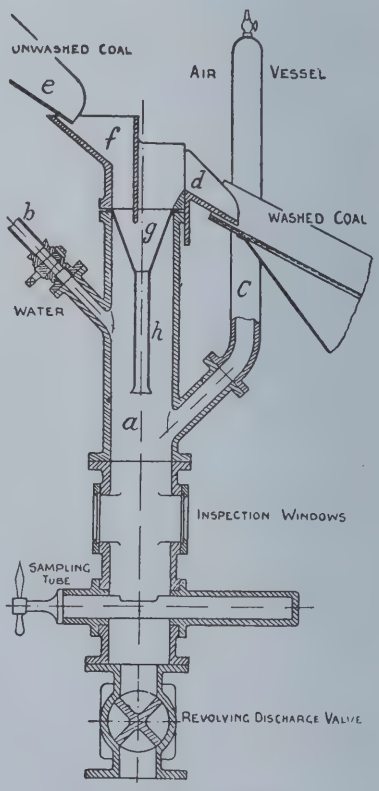


FIG. 4.—*Draper Washer.*

hour according to the percentage of dirt in the coal and to the degree of classification required. The concentrating table is particularly suited for the treatment of recrushed intermediate products, such as interstratified coal rejected by a washer dealing with the larger sizes. The water required for the washing operation amounts to about 250 gallons per ton of coal treated and the power consumption is very low being only about 2 H.P. for a table treating 10 tons of coal per hour. As an indication of what can be expected from the installation of a concentrating table, the following figures obtained with an H.H. Overstrom table, working on a Lancashire coal, may be cited:—

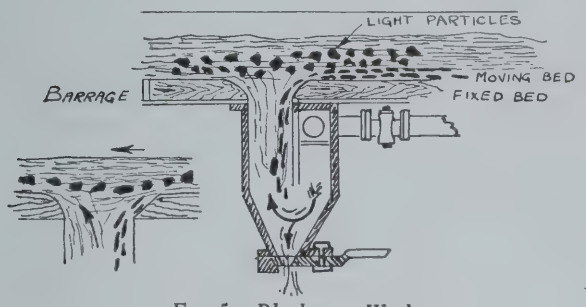


FIG. 5.—*Rheolaveur Washer.*

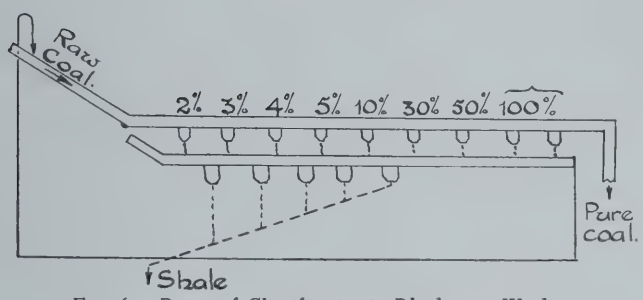


FIG. 6.—*Degree of Classification in Rheolaveur Washer.*

	Percentage of sample.	Ash in fraction.
Coal before treatment. Ash on dry coal, 35.7 per cent.		
Under 1.40 sp. gr.	55.3	3.3
Intermediate, 1.4-1.6 ...	4.4	18.0
Dirt, over 1.60	40.3	82.1
Clean coal. Ash on dry coal, 3.2 per cent.		
Under 1.4 sp. gr.	96.9	2.5
Intermediate, 1.4-1.6 ...	2.5	23.0
Dirt, over 1.6	0.6	42.0
Middlings. Ash on dry coal, 53.8 per cent.		
Under 1.4 sp. gr.	5.7	10.0
Intermediate, 1.4-1.6 ...	15.4	29.9
Dirt, over 1.6	78.9	61.7
Dirt. Ash on dry material, 84.1 per cent.		
Under 1.4 sp. gr.	0.1	5.0
Intermediate, 1.4-1.6 ...	0.15	22.0
Dirt, over 1.6	99.75	84.3

Comment is needless on the efficiency of separation when the proportion of coal in the dirt and of dirt in the coal are observed.

Another principle which is utilised in the washing of coal is that of upward-current classification. In such machines, the mixture of coal and shale is fed into a tube in which it meets an ascending current of water, so arranged that the coal is washed upwards by the water current, whilst the shale is of sufficiently high specific gravity to descend against the action of the current. The best known machine, acting purely on this principle, is the Draper washer, shown diagrammatically in Fig. 4. It will be seen that the separation is effected by means of a very simple device, consisting of an inverted plain or perforated cone (*g*) attached to a straight length of pipe (*h*) in which the greater velocity creates a zone of maximum lifting effect, below which only the heavier particles can descend, and in the cone itself the decreasing velocity produces a minimum lifting effect, being just sufficient to float the lighter particles over the sill into the chute (*d*). It is evident that only a short fall is necessary against the upward current to effect separation, because the velocity is too low at the bottom of the cone to prevent the gravity velocity of the falling heavy particles of shale descending, but too high to permit of the coal reaching the tube (*h*) and just sufficient to carry it over into the chute (*d*). In this machine, as, indeed, in all coal washing machines, regular feed is essential, since flushing with heavy charges of raw coal leads to choking of the tube or cone. The figures given in Table I. may serve as a guide to the quantity of water required and coal washed per hour in the Draper washer.

As an indication of the results obtained on the treatment of fine coal on this type of washer, the figures in Table II. are of interest.

In the Rheolaveur washer a combination of trough washing and upward classification is practised. The raw coal is fed into an inclined trough together with a current of water. As already indicated, the

coal is washed down the trough, whilst the shale settles out in the floor of the trough. The problem is to remove the shale continuously, and this has been effected in the Rheolaveur in a very ingenious way.

TABLE I.

Size of coal.	Approx. water velocity in ft. per sec.	Size of tubular extension of cone.	Water used. Galls. per minute.	Coal capacity. Sp. gr. 1.3.
1¼in.	0.79	4in.	25.0	4-5 tons/hour.
⅝in.	0.58	4in.	19.0	5-6 ,,
¼in.	0.35	2in.	2.84	2-3 ,,
1/32in.	0.124	2in.	1.00	2 ,,
1/32in.	0.124	4in.	3.85	6-8 ,,

TABLE II.

Size and class of product.	Speed of upward current.	Ash in raw coal.	Ash in clean coal.	Ash in shale.
1/60in.—1/100in.	1.30in./sec.	16.35%	3.60%	80.3%
1/10in.—1/30in.	4.10 ,,	15.37%	2.40%	80.0%
1/10in.—1/30in. (anthracite).	4.5 ,,	11.46%	2.00%	88.5%

Considering Fig. 5, it will be seen that the light particles of coal have a considerable forward impulse which carries them forward over the slot in the base of the trough. The heavy shale, however, has a low linear velocity, and it therefore falls into the slot. Here it escapes from the influence of the impulsive action of the horizontal current in the trough and thus tends to drop to the bottom of the slot. In the slot, it will be seen that an upward current of water is provided which, whilst allowing the shale to fall, is of sufficiently high velocity to cause any coal present to travel upwards and so join the main stream once more. In this way, the pure coal is finally delivered at the lower end of the trough, whilst the shale is evacuated steadily through valves placed at the foot of the various slots. A series of slots are provided so that gradual classification is obtained. The shale discharged, together with the water passing through the slots, falls into a second trough where a secondary washing process is carried out, the plant thus being operated in "battery cascade." Fig. 6 shows the gradual concentration of the pure coal in a series of Rheolaveurs, the figures indicating the percentage of pure coal in the product passed forward at any particular stage.

Slurry and washery effluents.

One of the main disadvantages of the wet method of coal concentration is the necessity for handling large volumes of water, and for dealing with the considerable quantities of sludge which are likely to be generated, especially when the coal is of a friable nature. In any case, when the coal contains as dirt a large proportion of clay or friable shale, such as often forms the roof or floor of a seam, the sludge produced in the washery is likely to give trouble. Large settling pits or labyrinths may be required, and the solid matter recovered from such pits may contain up to 50 per cent. of water, rendering it quite unfit for any use even at the colliery. The amount of water used at a colliery may vary from two to ten tons per ton of coal employed, although in exceptional cases it may be as low as one ton per ton of coal washed. The amount of fines produced will average, in Great Britain, about 8-12 per cent. of the tonnage handled. In some cases, where the coal is much more friable than the associated mineral matter, the fine material produced may be sufficiently low in ash to find a market if it can be recovered in suitable form. This is

more and more an economical possibility in view of the extended application of pulverised fuel firing, where coals of low calorific value can be handled successfully. The fine material also requires very little grinding, once it is obtained in the dry state. Even where Lancashire boilers are installed at collieries, modern forced draught furnaces can deal so satisfactorily with low-grade fuels that it is becoming more and more imperative to burn every scrap of combustible matter available. In such cases, the water carrying the material in suspension may be fed into a Dorr classifier, which removes the coarser material and discharges its overflow into a Dorr thickener usually located in a concrete tank, where the feed is treated continuously, clarified water returning to the washery, whilst the recovered solids are discharged as a thickened slurry of fine coal containing 50 per cent. or so of water. This slurry is best de-watered to a condition suitable for marketing, or for mixing with coal of larger size for coking or other treatment, by methods to be described later.

FIG. 7.—*Concentrating Tables handling underflow from Dorr Hydro-separators.*

Alternatively, the fine coal produced must be reduced in ash before it is marketable. The proportion of ash in fine coal almost invariably increases with increasing fineness, as is shown by the following figures on dried solids from a Dorr thickener underflow:—

TABLE III.

Size, mesh I.M.M.	Per cent.	Per cent. cumulative.	Per cent. ash.
On 30 mesh.	2.65	2.65	3.20
— 40+60 mesh.	11.55	14.20	3.52
— 60+80 „	16.25	30.45	3.90
— 80+100 „	16.55	47.00	5.20
—100+200 „	31.80	78.80	6.80
Through 200 mesh.	21.20	21.20	25.40
	100.00		

The material collected by handling in thickeners may be improved in quality by removing a proportion of the finer and slower-settling material in a hydro-separator. This calls for the use of two

thickeners in series, the first of which functions as a hydro-separator and the second as a clarifier for the turbid overflow from the first. The discharge from the first machine is the valuable product—along with that recovered by the classifier—whilst the underflow from the second machine is waste.

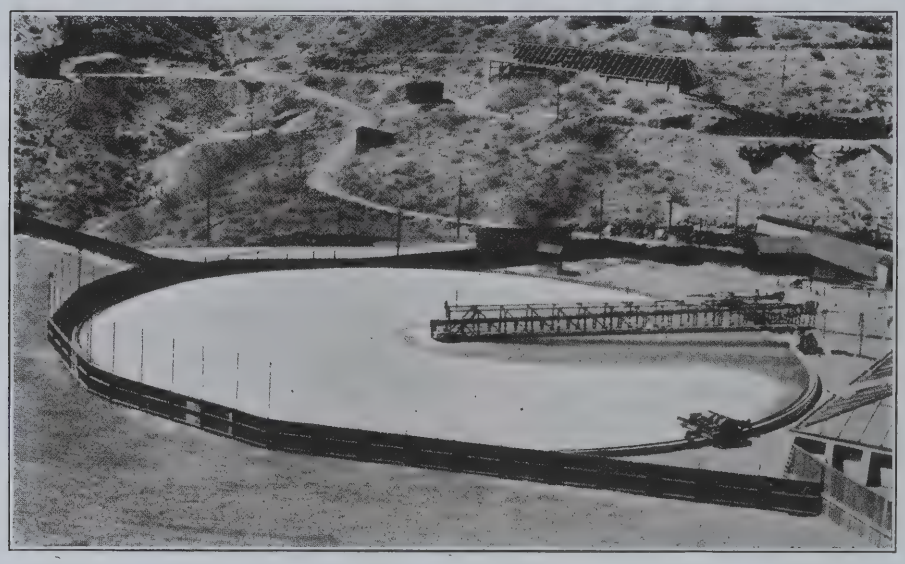


FIG. 8.—*The Dorr Traction Thickener.*

Another method of dealing with the recovered solids from the Dorr thickener is to pass the solids over concentrating tables, as illustrated in Fig. 7. The fine coal (over 60 mesh), together with sufficient water for table feed, are passed to the tables where high ash impurities are removed as described before. The fine coal goes to a Dorr classifier, where it is discharged with about 35 per cent. of water, this being reduced to about 15-20 per cent. after 24 hours draining. Very fine solids may be treated by the flotation process, in which a mixture of coal and water in the proportion of about one to four is treated in a flotation box, the mixture being violently agitated. A small proportion of oil is added to the mixture and the effect of the operation is to cause the coal to float in the form of a froth, produced by the emulsification of the oil, the clinging of the oil to the coal particles as nuclei and the presence of air, whilst the heavier shale is unaffected by the oil and sinks. The coal thus recovered may be used for briquetting, as is done in one of the South Wales collieries at present, or after de-watering, may be mixed with other coal for coking.

The Dorr continuous thickener is used for the continuous separation of fine solids from suspensions in liquid. The earliest machines were built to clarify solutions obtained in the cyaniding of gold ores, but they have now been adopted to the clarification of coal slurries. The machine consists of a round tank in which a slowly-revolving mechanism sweeps the settled solids to a central discharge opening by means of ploughs. The feed enters continuously through a feedwell located at the centre of the machine, and so constructed as to minimise disturbance of the liquid in the tank. Clarified water overflows into the peripheral launder continuously, whilst the removal of the discharged solids is effected by a Dorrco diaphragm pump. Should an overload of solids take place, an automatic alarm is operated, whilst simultaneously, the whole scraping mechanism can be raised clear of the bottom of the tank by means of a special lifting

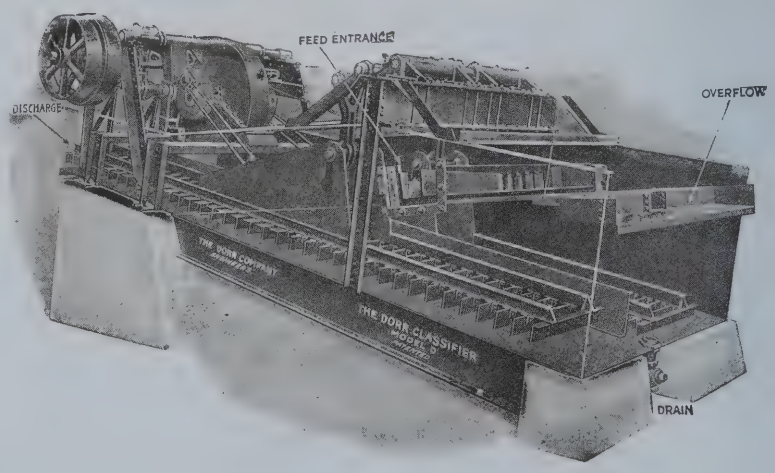


FIG. 9.—*The Dorr Classifier.*

device. In the Dorr traction thickener, shown in Fig. 8, the scraping mechanism, instead of being suspended from a superstructure, is carried by a truss pivoted on a centre column and supported at its outer end on a carriage moving round a track on the circumference of the tank. The drive unit consists of a spur gear speed reducer which is driven by a motor through a silent chain reduction, and this in turn drives the traction wheel through a flexible coupling. The feed is to the centre of the machine and an automatic electrically controlled by-pass is incorporated which diverts the feed should the motor be greatly overloaded or the power go off.

The hydro-separator is a thickener so designed as to have insufficient area to settle the finer and slower settling solids, whilst the larger and faster-settling particles. The Dorr classifier, shown in Fig. 9, like the Dorr thickener, was first used in the metallurgical industry, but is now applied to colliery practice. The machine consists of a tank, in the form of a settling sloping trough open at the upper end. The feed of solids of various sizes suspended in liquid enters the machine continuously through a feed launder situated at the periphery. The slower - settling solids, together with the bulk of the liquid, overflow at the closed end, while the granular material settles and is conveyed along the bottom of the tank by rakes actuated by a reciprocating mechanism and is finally discharged at the open end of the trough. The separation effected can be varied by changing the slope of the bottom, the speed of the rakes and the proportion of solids to liquids in the feed. A Dorr thickener of 200ft. diameter will have a daily capacity of 3,000 to 4,000 tons of solids contained in 5 to 6 million gallons of water. The power consumption is 3 H.P., and one man can supervise the working of the whole plant.

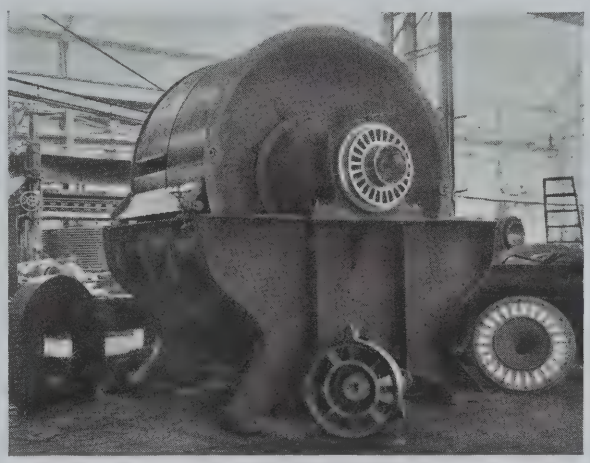


FIG. 10.—*Wolf Filter.*

Another method of dealing with both washery effluents and fine coal sludges is to use some form of continuous mechanical filter, illustrated in Fig. 10. Such a filter may be fed with thickened slurry from a Dorr machine or with wet fine coal from either concentrating tables or from the flotation process. Flotation fines are being treated on such machines to an increasing extent on the Continent, and at the Dutch State mines, for example, there are 20 of these filters. In the Wolf filter a rotating suction drum dips into a trough, from which it draws the crude slurry. As the drum emerges from the trough, air is drawn through the layer adhering to the drum and carries with it the liquid portion of the mixture. Agitating gear is provided in the trough to prevent any settling of the solids and as the drum revolves, immediately before re-immersion in the trough, a knife edge removes the cake of de-watered fine coal. These machines are made in sizes up to 200 sq. ft. of available filtering area, such machines handling quantities of 10 tons per hour of fine coal. The filtering medium may consist of fine bronze gauze or of stout cloth, and the filtered liquor can be returned to the washery without further treatment, as it is perfectly clear and free

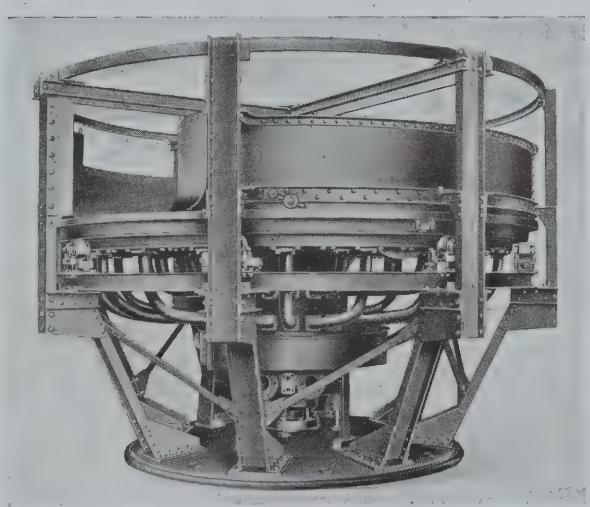


FIG. 11.—*Planfilter.*

from suspended matter. Where larger coal has to be de-watered, for example, of eighth-inch size, a Planfilter is used. This is illustrated in Fig. 11, and it will be seen to consist of a revolving table, the bed of which consists of perforated metal, covered with fine gauze or cloth. The table deck is divided into segments, each of which is connected with a suction pipe, so that natural drainage of the coal is assisted by the vacuum exerted on the underside of the table. With this machine, large outputs up to 20 tons per sq. yard per hour can be obtained. Another type of de-watering machine consists of a sloping deck, provided with barriers, the deck being given a reciprocating motion by suitable mechanism, such as, for example, an unbalanced pulley. The bottom of the deck is built up of wedge wire segments, this special type of mesh affording quick and efficient drainage, besides ensuring that no particles of solid matter can lodge in the openings by virtue of their peculiar construction. Coal of $\frac{1}{4}$-in. size can be dehydrated down to about 8 per cent. of water on such a machine with an expenditure of about 2 H.P. for a quantity of approximately 10 tons per hour.

Centrifugal machines are also used for the dehydration of washed coal, of which the Carpenter centrifuge may be taken as typical. The machine consists of a stepped truncated cone, driven by a vertical shaft and enclosed in a vertical casing. The coal falls from the feed hopper on to a horizontal revolving distributing disc fixed to the vertical shaft which can be so adjusted that the orifice between the cone and the edge of the disc ensures an even distribution with varying qualities of coal. The coal is thrown from the distributing disc by centrifugal force against the top screen where a portion of water passes through, being collected in a launder surrounding the machine. The partially dried coal travels down the inside of the machine until it reaches the first cascade, where it is broken up by serrated teeth to be redistributed to the following screen. This process is then repeated on successive screens, which consist of $\frac{1}{8}$-inch steel plate, perforated with $\frac{1}{8}$-inch holes at $\frac{3}{16}$-inch centres. The shaft is driven at 350 r.p.m., and the nominal capacity of the machine is 50 tons per hour and the machine absorbs about 65 H.P.

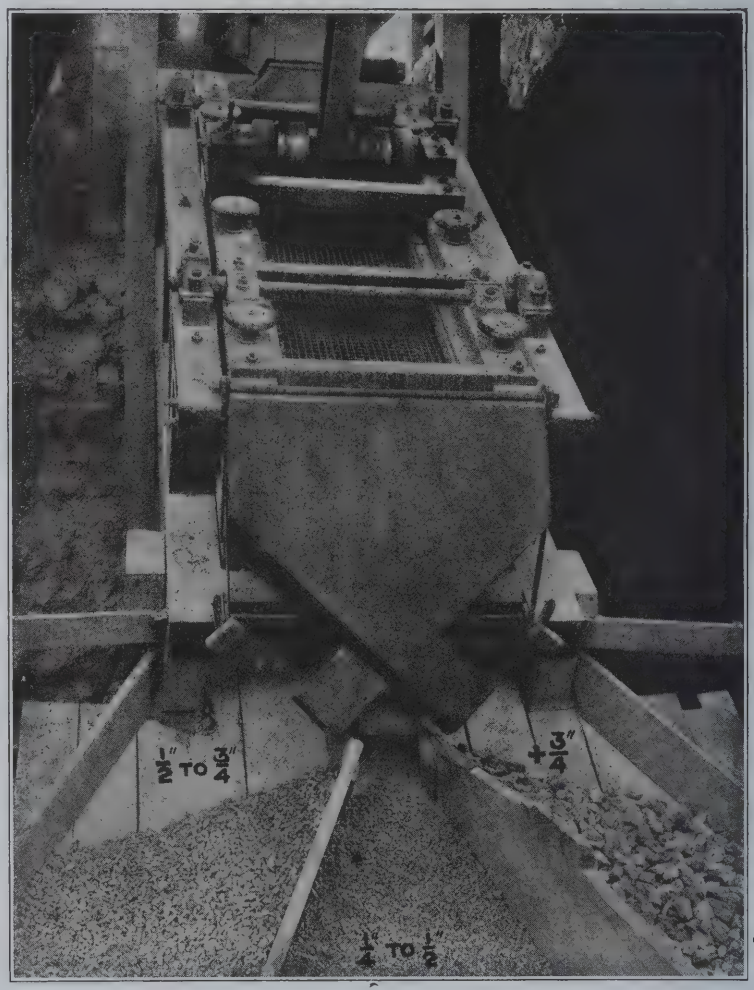


FIG. 12.—*H.H. Screen.*

If further drying of the coal be necessary, as when the coal is to be ground for firing in a pulverised fuel installation, some form of direct- or semi-direct-fired dryer must be used. Dryers are of two main types, horizontal and vertical cylinders. In the horizontal dryer, the coal is fed into one end of a slightly inclined cylinder, fitted inside with either staggered angle irons, or with some special trickling device. As the cylinder revolves, the coal is continually turned about and broken up, hot gases being passed through the cylinder at the same time. Indirect-fired dryers are usually used for coal drying, and they may be

used in conjunction with either a separately fired furnace or waste heat may be utilised, as flue gas may be available. The vertical type of dryer consists generally of a vertical stationary steel shell, provided with a central revolving shaft, carrying rabble arms which work the coal backwards and forwards over a series of tables or shelves. As the coal descends the dryer it meets an ascending current of hot gas, the moisture-laden gas being sucked off from the top of the dryer by means of a fan and exhausted into a cyclone, where any dusty coal is recovered. The vertical type of dryer is on the whole more economical than the horizontal type, as it occupies far less ground space, requires less power for operation and costs less in the first place. The loss of coal from breakage is also less, as will be appreciated when one considers the constant tumbling action to which the coal is submitted in the horizontal revolving cylinder. The fuel consumption of these drying machines varies between 7 and 10 pounds of water evaporated per pound of fuel burnt in the furnace of the dryer. Where pass-out steam is available, steam dryers may be used, these usually consisting of vertical dryers, the shelves being steam-heated, whilst the rabbling arms are also formed of steam pipes. Such dryers are used to a considerable extent in the lignite industry in Germany, where large volumes of low-pressure steam are usually available.

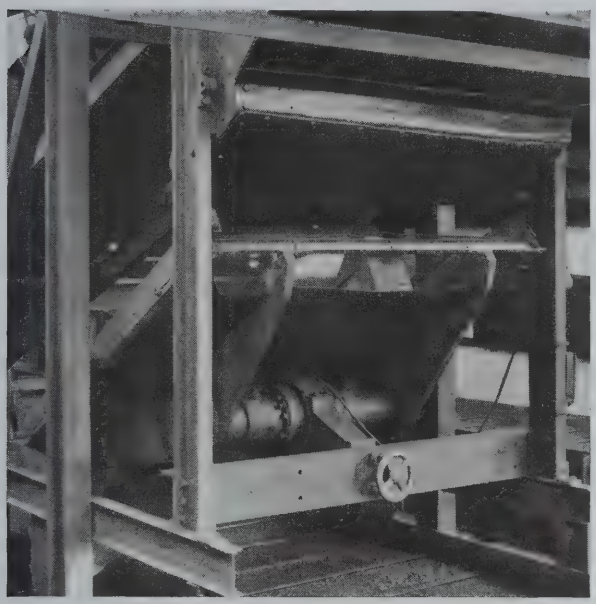


FIG. 13.—*Rear view of "Huwod" Screen shewing Feed Hopper.*

The screening of small coal.

It has already been mentioned that opinions are divided as to the advisability of screening coal before washing, some authorities holding that screening *after* washing is the only satisfactory method of dealing with the coal. In any case, the screening of small coal calls for rather different methods of procedure from those adopted when dealing with large coal.

Vibrating screens are coming into more and more extensive use every year for this purpose. Large coal is usually screened either in horizontal trommel type screens or else on jigging screens, but small coal has to be screened with a smaller screening area per ton of material treated, as on the normal type of jigging screen the area required for effective distribution of the small coal would be prohibitive.

Such vibrating screens include the H.H. Overstrom, Huwod, Hummer, Mitchell, Moto-Vibro and Newaygo units. The mechanism of the H.H. Overstrom screen, illustrated in Fig. 12, consists of an unbalanced pulley revolving at 1,600 r.p.m., on a stationary hollow vanadium steel shaft, fixed rigidly to and across the screen body. Two hollow shafts, fixed across the body of the screen, rest in coil springs, fitted into castings bolted on to the rigid outer supporting frame of the screen. The vibratory movement is set up by the revolution of the unbalanced pulley so that as the coal falls down the inclined screen mesh (set at about 37° to the horizontal) it is kept in a state of constant agitation, without actually dancing on the screen. The result is that the screen does not blind up and the coal rapidly classifies itself, the fine material quickly passing through the mesh. Such a screen of 10ft. by 4ft. size will handle about 50 tons of coal per hour.

The actuating mechanism of the Huwod screen, illustrated in Fig. 13, is electrically operated. The screen motor is a ½ H.P. motor, wound for 3-phase circuits, so that it is suitable for direct connection to any 3-phase low-tension network, provided the frequency is anywhere between 40 and 60 cycles. Where only D.C. is available, a small generator is supplied to generate the necessary alternating current.

The Hummer screen makes use of a special 15-cycle generator and the colliery engineer has to make his choice as to whether he prefers a purely mechanically-operated screen or one necessitating electrical apparatus, however reliable the latter may be.

All vibrating screens, of whatever type, should be fed with a regular feed and the material should descend the screen in the form of a sluggish river, so that the oversize is freed from undersize just before the foot of the screen is reached. In general, it will be found that over 70 per cent. of the undersize is removed in the first 25 per cent. of the screening area, the remaining area being required for removing that portion of the coal which lies very close in size to the aperture of the mesh provided.

Chapter 4.

THE BRIQUETTING OF COAL.

By Arthur Grounds, B.Sc., A.I.C.

Briquetting is a process which is resorted to in order to enhance the value of small coals which would otherwise be unsuitable for industrial use. For this purpose, the coal is generally mixed with a binding material to give the necessary degree of cohesion, although in at least one process no binder is used and the coal is simply subjected to high pressure to form a coherent block. Caking bituminous small coals can, of course, be utilised both for coking and for steam raising without further treatment, since under the action of heat they cake together to form a solid mass. With anthracite, dry steam coals and non-caking bituminous coals, however, considerable trouble may be experienced, since on firing with such coals, unless special firebars be used, high losses of unburnt fuel may occur.

The requirements of a good briquette are as follow :—It must be mechanically strong and must withstand rough handling, trans-shipment and loading with less than 10 per cent. breakdown. Indeed, in some contracts for the supply of briquette fuel, a breakage of 5 per cent. is given as the maximum allowable figure.

It must be waterproof and weatherproof, since breakdown by rain or weathering would lead to serious diminution in value. It must be practically smokeless on combustion, and must, at the same time, hold together in the fire until combustion is complete. The calorific value of the briquette fuel should not be less than that of the coal from which it is prepared.

The coal used for the preparation of the briquette should be so blended that clinkering does not take place on combustion. The cost of manufacture should be so low that the briquette fuel can be marketed at a price below that of the large coal of similar character available in the marketing area.

From the above considerations, it will be appreciated that certain precautions must be taken when selecting the coals suitable for briquetting. For example, anthracite alone would not give a satisfactory briquette, since it is entirely non-caking, and even with the addition of 10 per cent. of pitch as a binder, the briquette fuel would fall to pieces in the fire. Accordingly, it is the practice when briquetting anthracite duff to blend the duff with about 10 to 15 per cent. of a strongly-caking coal, together with about 9—11 per cent. of pitch. When the briquette is placed on the fire, the pitch, being the most volatile constituent of the fuel, burns off readily, and in so doing creates enough heat to lead to the carbonisation of the caking bituminous coal in the mixture. This coal then agglomerates the fine anthracite coal and produces a coherent mass of coke which burns slowly and steadily for hours, until the whole of the carbonaceous matter has burnt off. In a good anthracite ovoid, the fuel should, if left to burn undisturbed, hold together until combustion is complete, when a fine ash will be left containing no combustible matter whatever.

Briquettes used for steam raising or for locomotive use are blended from a variety of coals. In South Wales, the chief centre of the briquetting industry, the mixture generally used consists of about 50 per cent. of steam coal, 20 per cent. of anthracite duff, 20 per cent. of bituminous caking coal and

10 per cent. of pitch. Such a mixture would give a finished fuel of approximately the following composition:—

Volatile organic matter	21.0%
Coke	79.0%
Fixed carbon	73.0%
Ash	6.0%

The above analysis assumes that the coals used in the preparation of the fuel have been washed on one of the washers described in the preceding section.

One great advantage of briquette fuel is that it can be prepared to any desired specification by blending suitable coals. For example, for certain types of boilers it may be desirable to have a long-flaming fuel. This can be prepared by the addition of long-flaming bituminous coals, whilst if it is desired to prepare domestic fuel, which shall last for a long time without attention and which shall be cheap, anthracite duff is used to the extent of about 80 per cent. of the fuel content, since this gives a fuel which emits a large proportion of its heat in the form of radiant energy.

Artificial fuel is made in a large number of shapes and sizes, varying from the boulet, weighing about 30—40 grammes (*i.e.*, 1—1½ozs.) to the large block of 28 lbs. weight. Between these two extremes are the normal ovoid, about the size of a hen's egg, weighing roughly 3—4 ozs., and the 10-lb. block, which is the size most favoured for locomotive requirements. Domestic fuel may be made either of plain ovoid form or of a special design, such as the " cushion," whilst numerous special shapes have been manufactured from time to time, the inventors claiming always that more complete combustion is secured with their particular shape.

The binder most commonly used for the manufacture of briquettes is coal-tar pitch, obtained either from coke ovens or gas works, and the grade suitable for the purpose is known in the trade as " medium soft coal-tar pitch, suitable for the manufacture of briquettes." The ash in a good pitch should not exceed 0.5 per cent., and a high ash content is usually indicative of the adulteration of the pitch with blast furnace pitch. This latter commodity is obtained in Scotland at those blast furnaces where bituminous coal is used direct for the production of cast iron. Blast furnace pitch is quite unsuitable for briquetting and several industrial disputes have arisen over the delivery of this material in place of coke oven or gas works pitch. The ash content of blast furnace pitch varies from 5 to 25 per cent., due to the evolution of dust from the furnace which contaminates the tar from which the pitch is prepared. The volatile matter content of a suitable pitch should be over 70 per cent, and the twisting point should be between 50 and 60° C. when determined in the following manner. A bar of pitch, 2ins. long by ½in. square cross section is immersed in water and the water is gradually heated up for a period of two minutes. The pitch is then withdrawn and a very slight pressure is exerted with the fingers in an attempt to twist it round. If the pitch is still too hard, the water is heated again until it has risen in temperature by another 5 degrees, when the pitch is re-immersed for another two minutes and retested. When twisting is possible with the least possible pressure of the fingers, the temperature of the water bath gives the twisting point of the pitch. The melting point of the pitch is determined by immersing a cube of pitch of ¾in. side, stuck on a No. 12 copper wire, bent horizontally, in a beaker of water. The water is gradually heated to give a rise in temperature of 5 degrees C. per minute. When the cube of pitch softens and drops to the bottom of the beaker, the temperature is noted and this is taken as the melting point. For a coke-oven or gas works pitch of suitable quality, the melting point should lie between 85 and 105° C. The solubility in carbon disulphide is determined by extracting 0.5 gramme of pitch with 200 c.cs. of carbon disulphide in a reflux condenser, heated on a water bath or electric heater for an hour. The flask is then removed and cooled and the liquor filtered through two filter papers. The precipitate of carbon is well washed with carbon disulphide, and the filtrate and washings are distilled. The residue contained in a tared flask is dried in a water oven and weighed and the percentage of soluble matter calculated. This figure should be in

the region of 66—84 per cent. Other tests are necessary for special purposes, but those cited are generally adopted. A typical analysis of a suitable pitch would be :—

Volatile organic matter	70.4%
Coke	29.6%
Ash...	0.3%
Fixed carbon	29.3%
Soluble in carbon disulphide	75.5%
Free carbon (100—above figure)	24.5%
Twisting point	56.5° C.
Melting point	97.0° C.

The amount of binder necessary varies with the coals used, and as a rule increases with the hardness of the coal. For example, 10—11 per cent. will be required for hard anthracites, about 8.5—9 per cent. for steam coals, and 6.5—8.5 per cent. for bituminous coals.

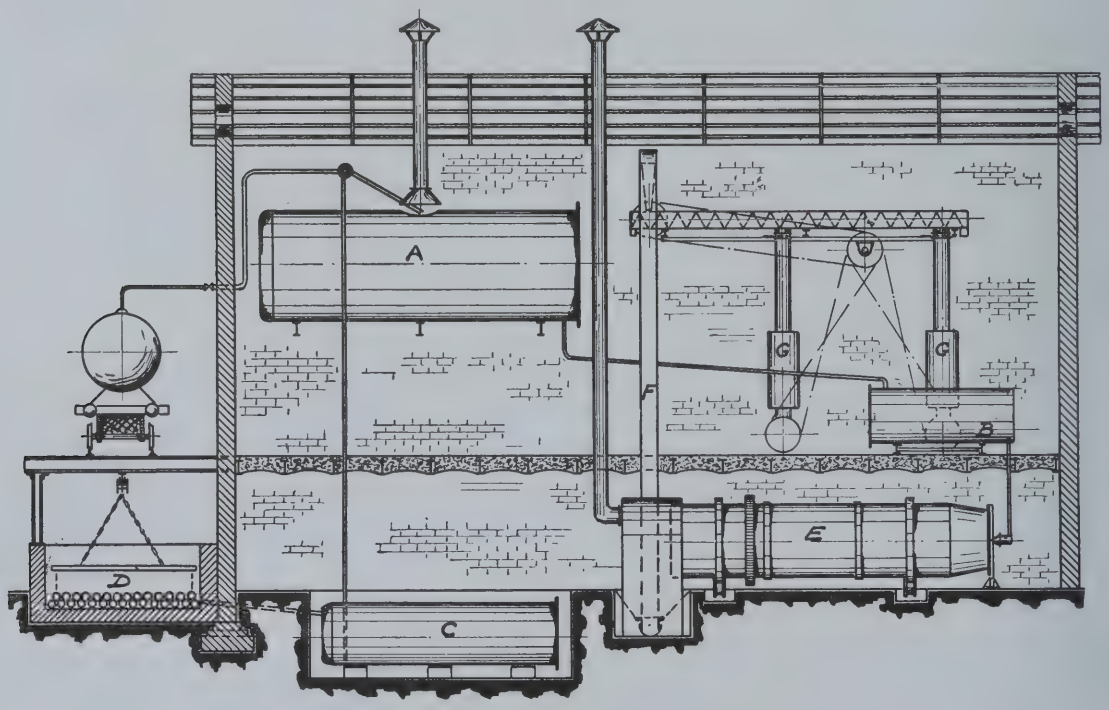
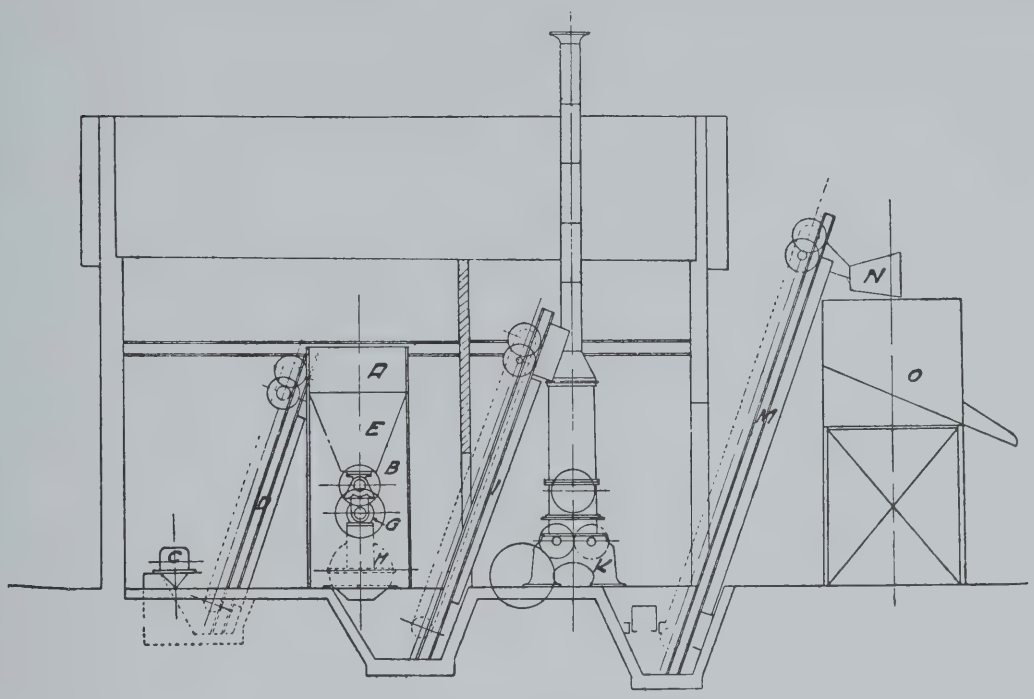


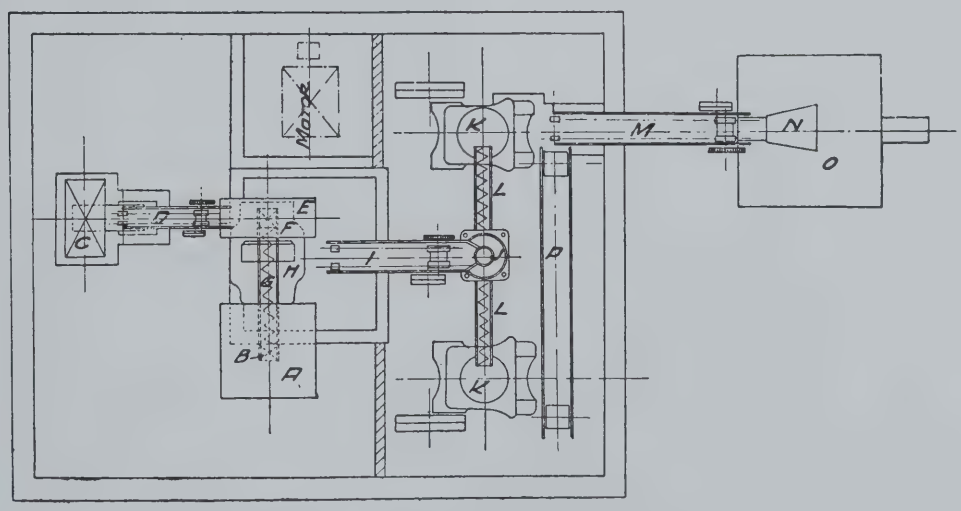
FIG. 1.—*Sectional Elevation of Briquetting Plant (Fohr-Kleinscmidt System).*

(A) Main Molten Pitch Storage Tank.
(B) Smaller Feeding Tank.
(C) Blowing Tank.
(D) Melting Box for Solid Pitch.
(E) Rotating Mixing Drum for Coal and Pitch.
(F) Elevator to Feed Presses.
(G) Presses.

The usual pressure adopted for the formation of briquettes using pitch as a binder is from 30 cwts. to 2 tons per sq. in. Bituminous coals can, however, be briquetted without the use of a binder if they be first ground to pass, say, 150 mesh, and then subjected to a pressure of about 10—12 tons per sq. in., taking care to extract all air during the pressing process. It should be explained that the crucial point in all briquetting operations is the cost of the binder, and for this reason many attempts have been made in the past to find a substitute for pitch. Inorganic binders are obviously unsuitable, since they are incombustible and lead to a diminution of the calorific value. Of the various organic binders proposed, starch has been used with some success, although this possesses the disadvantage that the briquettes after formation require to be cooked at a critical temperature to render them weatherproof. If this temperature be exceeded, the binder chars and the briquettes are not mechanically strong, whilst if the temperature



Sectional Elevation of Plant for Producing Ovoids.



Plan of Plant for Producing Ovoids.

FIG. 2.

(A) Coal Bin.
(B) Coal Feed Measure.
(C) Pitch Consumer.
(D) Bucket Chain Elevator, to lift Pitch from Crusher to Bin.
(E) Pitch Bin.
(F) Pitch Feed Measure.
(G) Spiral Conveyor.
(H) Carr Crusher.
(I) Bucket Chain Elevator, to lift from Mixer to Kneader.
(J) Kneader and Superheater.
(K) Ovoid Press and Distributors.
(L) Spiral Conveyor.
(M) Bucket Chain Elevator to carry Ovoids to Storage Bin.
(N) Trommel.
(O) Storage Bin.
(P) Belt Conveyor.

be not reached the briquettes become soft in rainy or damp weather. A new binder was recently described by Goodwin and White, this being produced by the fermentation of tropical vegetation, but again it is doubtful whether the cost of fermentation and importation is low enough to warrant such a binder being regarded as a solution of the problem. Sugar residues, mucilage, Irish moss, and waste starch have all been tried, but either the supply is seasonal or else the binder is not satisfactory from other standpoints.

The coal used is generally crushed in a disintegrator of the fixed beater or swing hammer type, whilst the pitch is broken up in a pitch cracker, falling on to a grating provided with longitudinal slots, through which protrude revolving arms which carry the pitch forward and crush it against the breaker-plate. The mixture of coal and pitch may be recrushed in a secondary crusher, and usually some form of measuring device is provided for the regulation of the proportion of pitch to coal. Such measuring device may consist either of a revolving table provided with a push-off plate or of worm conveyors with definite capacities. The coal should not be too finely ground as the production of floury coal leads to the consumption of an undue amount of power and also necessitates the mixture of a high proportion of pitch for binding. The pitch, however, should be ground as finely as possible in order to merely coat the coal grains with the thinnest possible layer compatible with satisfactory cohesion. In order to ensure this thorough distribution of the pitch, the Fohr-Kleinschmidt process involves the use of pitch-melting tanks, the pitch being then sprayed into the mass of coal which is kept in constant motion in a rotating trommel. Such a scheme is illustrated in Fig. 1.

In the normal process the mixture of coal and pitch is heated in a pug mill, where the mass is subjected to the action of both saturated and superheated steam, kneading knives thoroughly mixing the constituents. Using steam at 400° F., the steam consumption for a press turning out 17—20 tons per hour of briquettes is about 2,200 lbs. Such a press absorbs about 45—50 B.H.P., and runs at a speed of 30—40 strokes per minute. Ovoid fuel is made in roll presses, the fuel mixture being fed between rolls after cooking, at a temperature just above that of the twisting point of the pitch, *i.e.*, about 70° C. The ovoids are caught on a shaker screen as they emerge from the press so that all fines are screened out, passing thence on to a transport band or conveyor to give them time to cool off, as otherwise they would fuse into a solid mass.

A typical installation for the production of ovoids is shown in Fig. 2.

The briquetting of lignite has received much attention in Canada. The Souris lignites are of very low grade in the raw state, but by carbonising at 600° C. a residue is obtained which resembles charcoal and which produces an excellent briquette on binding with pitch and pressing in a roll press. The size of the lignite used is under 1/10-in. mesh, 60 per cent. of the material sizing between 1/10 and 1/20-in. mesh. The binders used are coal tar and petroleum pitches, with sulphite liquor and various waste flour residues as subsidiary bodies. The quantity of binder required however is much higher than that which is necessary for the production of ovoids from anthracite fines, and this would seem to be a critical factor where the cost of pitch is high. It was found that 13 per cent. of coal-tar pitch was necessary to produce a sound fuel. The strength of fuel is usually measured in an empirical way by the " cohesion test." This is carried out by revolving 100 lbs. of the fuel in a horizontal drum, 3ft. long and 2ft. 6ins. diameter, provided with three internal ribs of angle iron, 6ins. deep, for two and a half minutes at 28 revolutions per minute. The fuel must be sawn out of the solid block into pieces 1 lb. in weight, and after the test is completed the residue in the drum is screened over a screen of $1\frac{1}{2}$-inch mesh, and the portion retained on the sieve is weighed. This weight, in lbs., is called the " cohesion value " of the fuel. The revolution of the drum is supposed to reproduce the rolling of a ship, the attrition in the drum corresponding to the attrition in the ship due to projecting girders, baulks, etc. The cohesion value should be not less than 55 per cent., and a good fuel will often average over a long period 72—82 per cent.

The chemical tests on fuel are carried out in the same way as on coal, and the reader should consult some standard work such as " Fuel," by Coste and Andrews, or " The Analysis of Coal and its By-products," by Illingworth, for details of the various tests.

PART III.—UTILISATION.

1. STEAM-RAISING AND POWER PRODUCTION.

Chapter 1.

THE THEORY OF COMBUSTION.

By R. Wigginton.

Most fuels contain the elements carbon, hydrogen and oxygen, either free or combined. A general equation for the complete combustion of such a fuel would be $C_xH_{4y}O_{2z}+(x+y-z)\ O_2 = xCO_2 + 2yH_2O$, the carbon being converted into carbon dioxide, and the hydrogen into water. Such an equation, however, merely states the initial and final states of the system, and takes no account of the intermediate stages, which are, usually, numerous and complex.

Only in the case of simple gases, such as carbon monoxide and hydrogen, can the combustion be considered to be a one-stage process, fairly well represented by the chemical equations:—$2H_2+O_2=2H_2O$, and $2CO+O_2=2CO_2$.

Even in the case of methane, the work of Bone and others has shown that the combustion is complex, involving first, the addition of oxygen and, subsequently, the decomposition of the oxygenated compounds. The sequence of changes seems to be:—

CH_4	—	CH_3OH	—	$CH_2(OH)_2$	—	H_2O+CH_2O	—	$H_2O+CO+H_2$
Methane.		methyl alcohol.		methylene glycol.		formaldehyde.		

followed by the burning of the hydrogen and carbon monoxide. A further complication is the formation of solid carbon particles, probably by the thermal decomposition of the methane; the subsequent combustion of these particles gives the methane flame its well-known yellow luminosity. Restricting the air supply, or sudden chilling of the flame, may enable carbon particles to escape combustion, thus giving rise to smoke and soot. Other hydrocarbons, such as those found in coal tar, give rise to smoke much more readily than does methane.

The formation and decomposition of an oxygenated compound appears to be a general feature of the combustion of a complex substance. Thus, in the slow oxidation of coal, such as leads to spontaneous ignition, the first action of the atmospheric oxygen is to unite with the coal, as is shown by the increase in the weight and the change in the properties of the coal, which becomes largely soluble in potash. The gaseous products of low-temperature oxidation, oxides of carbon and water vapour, are formed by the decomposition of the oxidised coal.

The high temperature oxidation of coal, in a fuel bed, is concerned with the action of oxygen on the carbonisation products of coal, rather than on the raw fuel. Here again, the work of Wheeler and of Langmuir shows that the first stage in the combustion of carbon itself (coke, for example) is the fixation of oxygen as a complex, which afterwards breaks down to carbon, carbon dioxide and possibly to carbon monoxide also.

Fig. 1 presents a fairly good picture of the state of affairs in the different zones of a fuel bed. In the first four inches of travel, the atmospheric oxygen has been completely converted into carbon dioxide:—$C+O_2=CO_2$.

Unless the fuel is in large lumps, loosely packed, free oxygen cannot survive for more than about this distance. Just before the complete disappearance of the oxygen, carbon monoxide makes its appearance, being obtained by the interaction between carbon and carbon dioxide:—$C+CO_2=2CO$.

(The co-existence of oxygen and carbon monoxide over the interval 3 to 4 inches, depends on the fact that both gases are at this point very much diluted with nitrogen and carbon dioxide, and only react very slowly with one another.) The reduction of carbon dioxide by carbon being an endothermic reaction, the gases and carbon become cooled. This cooling, assisted by the increasing dilution of the carbon dioxide, finally brings the reaction, practically, to a standstill in the upper part of the fire. The final product is a sort of low-grade producer gas containing, in this instance, CO 12 p.c., CO_2 5 p.c., to burn which a secondary air supply over the fuel bed must be provided.

One of the most striking of combustion phenomena, is the constancy of the thickness of the oxidising zone, where free oxygen is present, whatever the rate of air supply. In experiments by the U.S. Bureau of Mines, the air supply was increased 40-fold, without affecting this thickness, although slight changes took place in the CO and CO_2 curves, as indicated in Fig. 1. Undoubtedly, this effect is a great, though usually unrecognised, help in the running of boiler furnaces at varying rates of combustion; a thin layer of carbon is capable of dealing with a very rapid stream of air. The explanation seems to be that the rate of combustion at high temperatures is limited only by the rate at which oxygen can diffuse through the thin, stagnant, burnt gas films which adhere to the surface of the lumps of carbon. Doubling the air velocity will decrease the film thickness, so that twice as much diffusion takes place—a compensation effect well known in diffusion experiments. Thus, when the air velocity is doubled, the rate of combustion is also doubled, and the oxygen is removed in the same distance of travel, as before.

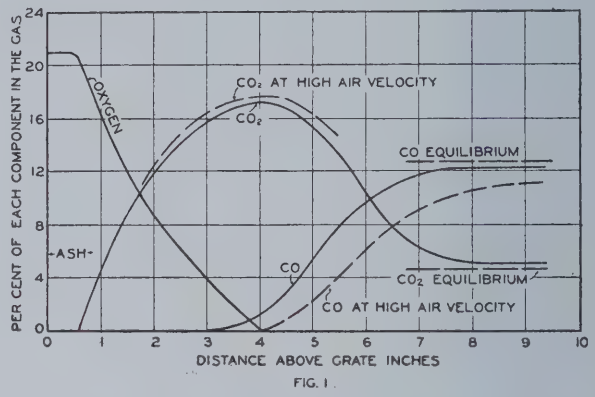


FIG. 1.

In the free gas space over the fuel, combustion has to take place, not only of the carbon monoxide from the coke residue, but, also, of the coal gas and tar distilled from the fuel in the upper part of the fire. This necessitates (1) a sufficient supply of secondary air; (2) adequate mixing of air and combustible gases; (3) ignition of the mixture and maintenance of it at a sufficiently high temperature for a sufficient period of time, i.e., adequate combustion space before the cooling of the gases.

An excess of air is always necessary, due largely to imperfect mixing. Moreover, a gas burning with a flame cannot remove the last traces of oxygen from the surrounding atmosphere, but becomes extinguished when a certain limiting percentage of oxygen is reached. For a methane flame, this percentage is unusually high—13.35 p.c. (the remainder being nitrogen), when the atmosphere is at the ordinary temperature; in the furnace a much lower value doubtless holds good, but it is unlikely that complete oxygen removal takes place. Other gases (CO, H_2) can burn in more dilute oxygen (the diluents have some influence on the result) but an "extinctive atmosphere" is, sooner or later, formed in all cases.

Flameless "surface combustion," in contact with incandescent solids (e.g., coke, brickwork) may take place rapidly even with dilute mixtures and probably plays a considerable part in the economy of the boiler furnace. Slow flameless combustion, throughout the body of a dilute gas-mixture, is also possible.

The higher the combustion chamber temperature, the more rapid will be the combustion, an importance consideration since the time available is so short. At high temperatures, however, combustion, though rapid, is never quite complete, owing to the dissociation of the products of combustion, causing a reversal of the reactions:—$2CO_2=2CO+O_2$; $2H_2O=2H_2+O_2$.

According to Nernst and v. Wartenburg, the extent of the dissociation, at 1,500 deg. C. and 1 atmosphere pressure, is 0.05 per cent. with carbon dioxide, and 0.02 per cent. with steam, and at 2,000 deg. C. the percentages are 2.05 and 0.58, respectively. In the detonation of a cyanogen-oxygen mixture, $C_2N_2+2O_2$, a flame temperature of over 4,000 deg. C. is reached, and the carbon burns to carbon monoxide only in the flame-front, the subsequent burning of the carbon monoxide taking place in the cooler region, behind the detonation wave. $C_2N_2+O_2=2CO+N_2$; $2CO+O_2=2CO_2$.

Similarly, in ordinary furnace combustion, if the gases are cooled gradually from the highest temperature, an opportunity is provided for the burning of the small quantity of carbon monoxide remaining; a fairly high temperature is needed, as, owing to the dilution, the reaction is slow. If, however, the gases are suddenly chilled, e.g., by premature contact with the water tubes of a boiler, appreciable quantities of carbon monoxide may remain, until the temperature becomes too low to allow of further combustion.

FLUE GAS CALCULATIONS AND THE REGULATION OF THE AIR SUPPLY.

Calculation of the Excess of Air.—While every fuel requires a definite proportion of air for complete combustion, the amount used in practice is often greatly in excess of the theoretical requirements, the surplus passing through the system unchanged. As already stated, a moderate excess of air is necessary to ensure complete combustion, but any further increase is disadvantageous, because the volume of hot chimney gases, and, consequently, the amount of heat carried away by them, is needlessly increased. From the composition and temperature of the flue gases, it is possible to reckon what excess of air is being used and how much heat is being carried up the chimney.

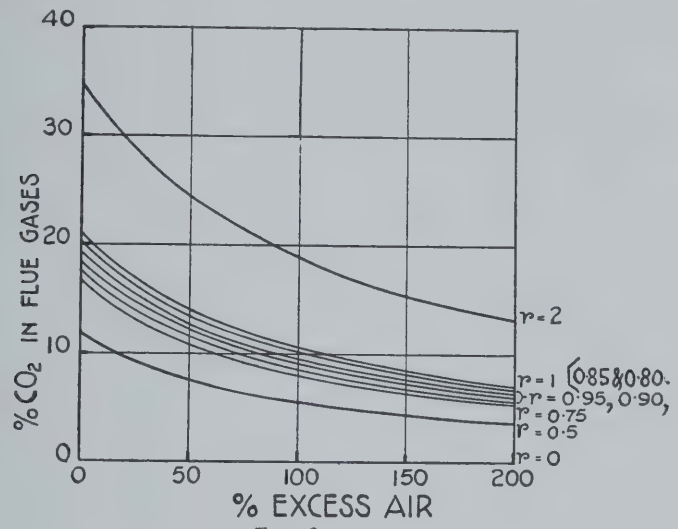


FIG. 2.

r	% EXCESS AIR 0	50	100	150	200
0	0	0	0	0	0
0·5	11·73	7·53	5·54	4·38	3·63
0·75	16·63	10·87	8·09	6·44	5·34
0·80	17·54	11·52	8·58	6·83	5·68
0·85	18·43	12·15	9·07	7·23	6·01
0·90	19·31	12·77	9·55	7·63	6·35
0·95	20·17	13·40	10·02	8·01	6·67
1·00	21·00	14·00	10·50	8·40	7·00
2·00	34·70	24·56	19·00	15·50	13·08

% CO_2 IN FLUE GASES.

TABLE 1.

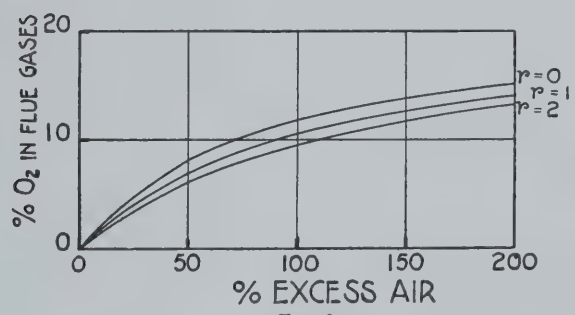


FIG. 3.

r	% EXCESS AIR 0	50	100	150	200
0	0	8·14	11·73	13·76	15·05
1	0	7·00	10·50	12·60	14·00
2	0	6·14	9·50	11·63	13·08

% O_2 IN FLUE GASES.

TABLE 2.

Supposing combustible gases to be absent, the presence of oxygen indicates that excess of air is being employed, and the nitrogen in the gases provides a measure of the total air supplied to the furnace. Since air contains 21 volumes of oxygen to 79 volumes of nitrogen, we have, per 100 volumes of flue gas:—

$$\text{Air supplied} = \frac{100}{79}\,N_2\,; \qquad \text{excess of air} = \frac{100}{21}\,O_2\,; \qquad \text{air used} = \frac{100}{79}\,N_2 - \frac{100}{21}\,O_2$$

$$\%\ \text{excess of air} = 100\left(\frac{100}{21}\,O_2\right) \div \left(\frac{100}{79}\,N_2 - \frac{100}{21}\,O_2\right) = 100\,\frac{O_2}{0.266\,N_2 - O_2}$$

In the above calculation, the symbols O_2 and N_2 are used to denote the volumetric percentages of these gases present in the flue gases. If combustible gases are present, the oxygen needed to burn them must be deducted from the oxygen present, before applying the formula. The chemical equations:— $2CO+O_2=2CO_2$; $2H_2+O_2=2H_2O$; $CH_4+2O_2=CO_2+2H_2O$; show that carbon monoxide and hydrogen each require half their own volume of oxygen for complete combustion, and that methane requires twice its own volume. The modified equation for use when these gases are present is, consequently:—

$$\%\ \text{excess of air} = 100\ (O_2 - \tfrac{1}{2}CO - \tfrac{1}{2}H_2 - 2CH_4) \div \left[0.266\ N_2 - (O_2 - \tfrac{1}{2}CO - \tfrac{1}{2}H_2 - 2CH_4)\right].$$

Table III.

Values of Ratios.

(1) Pure Substances.

Substance.	r	s	t
C	1	3,051	1.071
H_2	0	4,337	1.321
CO	2	4,262	1.352
CH_4	0.5	3,309	1.196
C_2H_4	0.6667	3,470	1.154
$C_6H_{10}O_5$	1	3,532	1.292

(2) Various coals (compositions calculated on dry ash-free basis, and one per cent. of nitrogen assumed to be present).

		Per cent. carbon.			
		96	90	84	72
Per cent. hydrogen.	2	r=0.9450 s=3,044 t=1.087	...	...	...
	4	...	r=0.8997 s=3,070 t=1.106	r=0.9152 s=3,061 t=1.116	r=0.9563 s=2,984 t=1.146
	6	...	r=0.8431 s=3,105 t=1.116	r=0.8529 s=3,079 t=1.126	r=0.8782 s=3,035 t=1.153

NOTE:—For moist coals, t should be increased by 0.00070 for every 1 part of moisture associated with 100 parts of dry coal; otherwise variations in ash and moisture do not alter these ratios. (The values of s given for coals are approximately the average values for the compositions indicated.)

Table IV.

Mean specific heats of gases at constant pressure, in 15° C. calories per gramme-molecule (from Partington and Shilling, "The Specific Heats of Gases," London, 1924).

Temp. Range.	Air, O_2, N_2 or CO	CO_2	H_2O	$\frac{CO_2}{air}$	$\frac{H_2O}{air}$
0 °C.	6.97	8.75	...	1.255	...
0—100° C.	6.97	8.95	9.09	1.284	1.304
0—200° C.	6.98	9.15	8.94	1.311	1.280
0—300° C.	6.99	9.35	8.84	1.338	1.265
0—400° C.	7.01	9.55	8.79	1.362	1.254
0—500° C.	7.03	9.74	8.77	1.386	1.247

If it should happen that the bracketed expression is negative, this means that less than the theoretical quantity of air is being supplied; the equation will then give the percentage deficiency.

In obtaining the above formulae, it was assumed that, all the nitrogen in the gas came from the air used for combustion, and none from the fuel. They are, therefore, only applicable to fuels containing small percentages of nitrogen. Most fuels, however, belong to this category,—wood, peat, lignite, coal, coke, tar, petroleum, water gas and coal gas may be mentioned, although the nitrogen percentage in the last-named is, sometimes, high enough to affect, appreciably, the accuracy of the calculation. For fuels like blast-furnace gas and producer gas, the method must not be used.

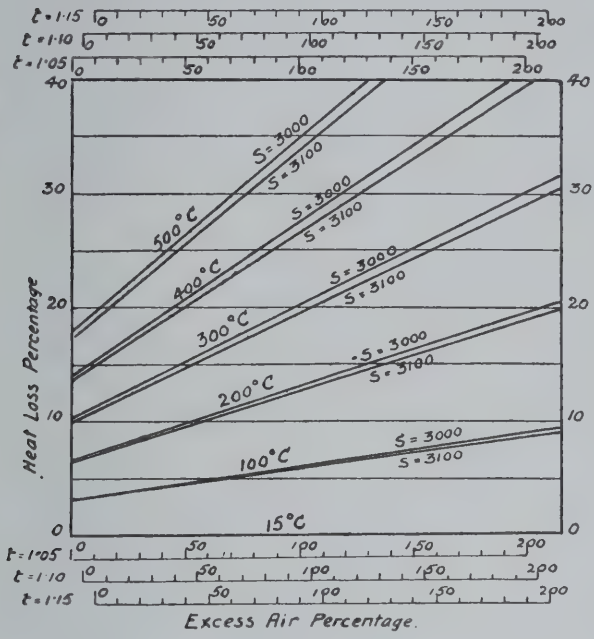


FIG. 4.

Applied to producer gas, the equation gives the excess of air, expressed as a percentage of that required to burn, not the producer gas, but the coal (or other fuel) from which it is made—for it makes no difference to the final gas composition whether the coal is burnt directly in one stage, or first gasified and then burnt completely, in the form of producer gas. Since in the two-stage process the " primary air " is anything from $\frac{1}{4}$ to $\frac{1}{2}$ of the total air, it is evident that the calculated percentage of excess air will require to be multiplied by a factor which lies between 4/3 and 2, in order to make it refer to the " secondary air " instead of to the total air. The reader may find it interesting to work out the exact factor, in any particular case.

Provided the air is in excess and only traces of unburnt gases are present, it is unnecessary to make a complete flue gas analysis, in order to determine the excess of air. A simple carbon dioxide determination is all that is required, and automatic machines for carrying out and recording such estimations at frequent intervals are in common use, and should form part of the equipment of all large boiler-houses. Unlike the foregoing method, however, this method requires some knowledge of the composition of the fuel.

TABLE V.

Percentage Heat Loss due to Excess of Air.

Temp.	Excess air 100%		Excess air 200%		Excess air 300%	
15	0	0	0	0	0	0
100	2.939	2.844	5.878	5.688	8.817	8.532
200	6.407	6.200	12.81	12.40	19.22	18.60
300	9.883	9.563	19.77	19.13	29.65	28.69
400	13.39	12.96	26.78	25.92	40.17	38.88
500	16.91	16.37	33.82	32.74	50.73	49.11
	s=3,000	s=3,100	s=3,000	s=3,100	s=3,000	s=3,100

Let r denote the volumetric ratio $\frac{\text{carbon dioxide formed}}{\text{atmospheric oxygen consumed}}$ both quantities referring to the complete combustion of the same weight of fuel; then if we consider the burning of such a quantity of fuel as requires 100 volumes of air for its complete combustion, and suppose that 100+x volumes of air are actually

supplied, the flue gases will consist of carbon dioxide, 21 r volumes, nitrogen 79 volumes, and unchanged air x volumes, total 21 r+79+x volumes. Evidently we have:—$\%CO_2$ in flue gases$=\frac{2100\ r}{21\ r+79+x}$; and conversely:—$x=\frac{2{,}100\ r}{\%CO_2}-21\ r-79$.

Here again, the fuel is assumed to be practically nitrogen-free. Table I. gives a number of results for various values of x and r, and these are shown, graphically, in Fig. 2. Oxygen percentages have also

TABLE VI.

Percentage Heat Loss with Theoretical Air.

Temp.	t=1.05		t=1.10		t=1.15	
15	0	0	0	0	0	0
100	3.086	2.986	3.232	3.128	3.380	3.271
200	6.728	6.510	7.049	6.821	7.369	7.131
300	10.38	10.04	10.87	10.52	11.37	11.00
400	14.06	13.60	14.73	14.25	15.40	14.90
500	17.76	17.19	18.61	18.01	19.45	18.82
	s=3,000	s=3,100	s=3,000	s=3,100	s=3,000	s=3,100

been worked out and plotted in Table II. and Fig. 3; and it can easily be proved that % O_2 in flue gases$=\frac{21\ x}{21\ r+79+x}$

Variation of the ratio r has, comparatively, little effect on the oxygen percentage, as will easily be seen from the graph. For pure carbon, r=1 as may readily be seen from the equation $C+O_2=CO_2$. Coke and charcoal, being nearly pure carbon, will also have, approximately, this value.

TABLE VII.

Values of Siegert's Coefficient (assuming r=0.884, s=3,070, t=1.12).

$\%\ CO_2$	K	$\%\ CO_2$	K
0	0.6290	10	0.6779
1	0.6339	11	0.6828
2	0.6388	12	0.6877
3	0.6437	13	0.6926
4	0.6486	14	0.6975
5	0.6535	15	0.7024
6	0.6583	16	0.7073
7	0.6632	17	0.7121
8	0.6681	18	0.7170
9	0.6730	19	0.7219

The same value will apply to cellulose (and, approximately, to wood); $C_6\ H_{10}\ O_5+6O_2=6CO_2+5H_2O$; also to a mixture of equal volumes of hydrogen and carbon monoxide (and, approximately, to blue water gas) $(CO+H_2)+O_2=CO_2+H_2O$.

For hydrogen, r=O, since no carbon dioxide is formed, while carbon monoxide has the value 2; $2CO+O_2=2CO_2$.

For methane the ratio is 0.5; $CH_4+2O_2=CO_2+2H_2O$, and the value for coal gas is similar, as the following calculation demonstrates:—

Gas.	Vol. of gas.	Vol. of O_2 used.	Vol. of CO_2 formed.
CO_2	1	0	1
Unsaturated hydrocarbons taken as			
C_3H_6	3	13.5	9
CO	8	4	8
CH_4...	30	60	30
H_2	50	25	0
N_2	8	0	0
Totals	100	102.5	48

$$r=\frac{48}{102.5}=0.468$$

For ethylene C_2H_4, r =0.667:—

$$C_2H_4+3O_2 = 2CO_2+2H_2O$$

Naphthenic petroleum, of composition $C_n H_{2n}$, will have the same value.

In the case of coals, r will usually lie between the limits 0.84 and 0.96, and, in default of more exact. information, an average value of 0.884 may be assumed, without serious error, for ordinary bituminous coal The exact value of r may easily be deduced from the composition of the coal, and several values, so obtained, are given in Table III. An example of the method of calculation is given later, but it may be noted here that coals, quite different in composition, may have almost identical values of r. Thus an ortho-lignitous coal (Seyler's classification) of composition C 77.5 per cent., H 5.4 per cent., O 16.1 per cent., and N 1.0 per cent., has r=0.886, while an ortho-carbonaceous coal of composition C 92.25 per cent., H 4.25 per cent., O 2.5 per cent., N 1.00 per cent., has r=0.887.

Instead of calculating r from the composition of the coal, it is also possible to make use of a complete flue gas analysis. If combustible gases are absent, we have, per 100 vols. of flue gas, oxygen used $=\frac{21}{79}\ N_2—O_2=0.266\ N_2—O_2$; and $r=\frac{CO_2}{0.266\ N_2—O_2}$

If combustible gases are present, the carbon dioxide must be increased by the amount that would be formed by their complete combustion, and the oxygen needed for this purpose must be deducted from that present in the gas. This gives the modified equation:—

$$r=\frac{CO_2+CO+CH_4}{0.266\ N_2—(O_2—\frac{1}{2}CO—\frac{1}{2}H_2—2CH_4)}$$

In cases when the air supply is deficient, the expression in the brackets will be negative, but the equation will still be valid, even if oxygen is entirely absent from the flue gas.

An example of the application of the formula may be given. Composition of flue gas:—

CO_2 12.45 p.c., O_2 5.78 p.c., CO 1.21 p.c., N_2 80.56 p.c.

$$r=\frac{12.45+1.21}{0.266\times 80.56—(5.78—0.605)}=0.840$$

Thus, a single complete flue gas analysis will provide the data for the exact interpretation of a whole series of carbon dioxide estimations, provided the fuel remains the same.

It may happen that the value of r calculated from the composition of the coal, is different from that calculated from the flue gas analysis. As a general rule, no significance can be attached to such discrepancies. If, however, the sampling and analysis of both the fuel and the flue gases are done with great care, and a long series of determinations of r, by both methods, are carried out and averaged, further useful information may be obtained; for, evidently, if r_2, the flue-gas value, is lower than r_1, the calculated value (from the composition of the coal), the proper volume of carbon dioxide (or the equivalent quantity of carbon monoxide or methane) per unit volume of oxygen is not being obtained on the large

scale; some of the carbon must be escaping combustion in the form of unburnt coal, cinders, tar or soot, and the amount lost in this way will be the fraction $\frac{r_1-r_2}{r_1}$ of the total carbon supplied to the furnace.

If the fuel contains sulphur, this, on combustion, will give chiefly sulphur dioxide:—$S+O_2=SO_2$.

In gas analysis, the sulphur dioxide is, invariably, estimated along with the carbon dioxide, so that in flue gas calculations sulphur should be reckoned as if it were 3/8 of its weight of carbon, this being the weight that would give a volume of carbon dioxide equal to the sulphur dioxide actually formed.

Calculation of the sensible heat loss. It will be noticed that, in the whole of the preceding discussion, the presence of water vapour in the flue gases has been ignored. This is because, whatever amount of water vapour they originally contain, gas samples are always analysed saturated with water vapour at the ordinary temperature. This condition is maintained throughout the analysis, with the result that the same percentage composition is found as if the dry gas were analysed.

When, however, it is a question of determining the sensible heat loss in the chimney gases, water vapour can no longer be ignored.

To calculate the sensible heat loss, it is necessary, first of all, to know the specific heats of the gases concerned. Table IV. gives this information, expressed in the form of calories per gramme-molecule of gas (i.e., per 32 grammes of O_2, 44 grammes of CO_2, and so on), a convenient unit, since 1 gramme-molecule of any gas occupies the same volume (22.41 litres at 0 deg. C., and 760 mm. barometric pressure). The table, also, gives the " air-equivalents " of unit volumes of carbon dioxide and water vapour, that is the volumes of air which are equal, in thermal capacity, to unit volumes of carbon dioxide and water vapour, respectively. This alternative method of expressing the specific heat data is useful, because the greater part of the flue gases consists of air, or nitrogen, and it is convenient to be able to express the remainder in the same terms.

Let us take as unit weight of fuel, the weight which requires 100 gr. mol. (or 2,241 litres) of air for its complete combustion, and suppose 100+x gr.-mol. is the amount of air actually employed. The excess of air x gr.-mol. will be unchanged, and if the flue gas temperature is T_2 and the atmospheric temperature T_1, the heat lost will be $x\ (T_2-T_1) \times$ specific heat of air. To express this loss as a percentage of the heat supplied by the fuel, we required to know the calorific value of the latter, calculated, not in the usual manner per gramme of fuel burnt, but per gramme of oxygen used in burning it. Calling this quantity s, we have the heat supplied by unit quantity of fuel is 21×32 s, since the 100 gr.-mols. of air contain 21 gr.-mols. or 21×32 grms. of oxygen. Therefore, the percentage heat loss, due to the excess of air only, is $x\ (T_2-T_1)\frac{100}{21\times32\,s} \times$ specific heat of air.

For various coals, s (which is unaffected by variations in the ash content) appears to vary only between the limits 2,980 and 3,110 cals. per gramme of oxygen used (see Table III). The average value of 3,070 cals. per gramme of oxygen used may be recommended to be assumed, in cases where the actual value is unknown. Table V. gives the results of a number of calculations of the percentage heat loss with various flue gas temperatures, excesses of air, and values of s.

The heat loss due to the theoretical air will be, roughly, the same as the further loss due to using 100 per cent. excess of air. To get the exact loss, suppose that t is the ratio of the heat capacity of the theoretical flue gas mixture ($N_2+CO_2+H_2O$) to the heat capacity of the air from which it was formed. Then the 100 gr.-mol. of air will give, on combustion, gases equivalent to 100 t gr.-mol. of air, and, therefore, the percentage heat loss is $100\ t\ (T_2-T_1)\frac{100}{21\times32\,s} \times$ specific heat of air.

It can be shown that for coals, t will lie between the limits 1.080 and 1.160, with an average value of about 1.120 (see Table III.). Table VI. gives some calculated results for various values of t.

The total sensible heat loss, viz.:—$(100t+x)\ (T_2-T_1)\frac{100}{21\times32\,s} \times$ specific heat of air, is shown in graphical form in Fig. 4, which corresponds to Tables V. and VI. The figure is self-explanatory, and

clearly exhibits the extent of the variations between different sorts of coal; they are far smaller than might, at first sight, have been expected.

Taking 6.99 as the average value of the specific heat of air, we have % heat loss$=\frac{100\times 6.99}{21\times 32\ s}$ (T_2-T_1) (100 t+x); and if we substitute for x the expression$\frac{2100\ r}{\%\ CO_2}-21\ r-79$, we obtain, after simplication:—% heat loss$=\frac{T_2-T_1}{\%\ CO_2}$ $(2184.\ \frac{r}{s}+1.040.\ \frac{1}{s}\ (100t-21r-79)\ \%\ CO_2)$. This gives heat loss, in terms of the temperature and carbon dioxide content of the flue gases. Siegert has proposed the formula % heat loss$=\frac{T_2-T_1}{\%\ CO_2}$. K, where K is usually taken as 0.65 or 0.68. By comparing the two equations, it will be seen that Siegert's coefficient is, actually, a function of 4 variables, r, s, t and the % CO_2. If we put r=0.884, s=3070, t=1.12 we get the simplified equation, % heat loss$=\frac{T_2-T_1}{\%CO_2}$ $(.6290+.004891.\ \%CO_2)$. From this we can tabulate values of K suitable for various percentages of carbon dioxide in the flue gases. This is done in Table VII. With the help of this table, approximate heat loss calculations may be made, which are near enough to the truth for many purposes, and useful, in all cases, as a rough check on more elaborate calculations.

It will now be convenient to consider the method of evaluating the quantities r, s and t; they are best calculated together, and a numerical example will serve to show the process. It is only necessary to bear in mind that 1 gr.-mol. (32 grms.) of oxygen, will react with either 12 grms. of carbon, or 4.032 grms. of hydrogen, giving, in the former case, 1 gr.-mol. of carbon dioxide, and, in the latter case, 2 gr.-mol. of water vapour.

Consider the burning of 100 grm. of coal:—

	grams.	gr.-mol. O_2 needed.	gr.-mol. CO_2 formed.	gr-mol. H_2O formed.
C	92.25	7.6875	7.6875	—
H	4.25	1.055	—	2.110
O	2.50	—0.078	—	—
N	1.00	—	—	—
	100.00	8.6645	7.6875	2.110

$\frac{CO_2\text{ formed}}{O_2\text{ needed}}=\frac{7.6875}{8.6645}=0.8874=r$ $\qquad$ $\frac{H_2O\text{ formed}}{O_2\text{ needed}}=\frac{2.110}{8.6645}=0.2435$

Now consider the burning of 100 gr.-mol. of air. The flue gases will consist of:—N_2 79 gr.-mol.; CO_2 $21\times 0.8874=18.63$ gr.-mol.; H_2O $21\times 0.2435=5.113$ gr.-mol. The air-equivalent of this mixture (adopting specific heats over the 0—300° C. range) will be:—

N_2	...	79 gr.-mol.
CO_2	$18.63\times 1.338=$ ...	24.92 ,,
H_2O	$5.113\times 1.265=$ ...	6.468 ,,
Total	...	110.388 gr.-mol.

This being obtained from 100 gr.-mol. of air, $t=\frac{110.388}{100}=1.104$

Furthermore, suppose the calorific value of the coal (determined in a bomb calorimeter) is 8,527 calories, per gramme. Since 100 grm. of coal require 8.6645 gr.-mol., or 32×8.6645 grm. of oxygen $s=\frac{8527}{0.32\times 8{\cdot}6645}=3076$ cals. per grm. of oxygen.

In the foregoing calculations of the sensible heat loss, no account has been taken of the latent heat of condensation of the water vapour in the flue gases. The additional loss due to this cause will be 579.5 calories per gramme of water vapour formed, and will, usually, be of the order of 3.5 per cent. of the calorific value.*

Losses due to incomplete combustion.—Besides the sensible heat loss, we must consider losses due to incomplete combustion. If the flue gases contain carbon monoxide as well as carbon dioxide, the fraction of the total carbon in the fuel which is converted into carbon monoxide will be $\frac{CO}{CO_2+CO,}$ since both gases (and methane also) contain the same weight of carbon per unit volume; CO and CO_2 represent the percentages of these gases, by volume, in the flue gases, as in previous formulae. As the heat lost in burning a gramme of carbon to carbon monoxide, instead of carbon dioxide, is 5683 cals. per grm. of carbon, we have:—% heat loss due to unburnt $CO = \frac{CO}{CO_2+CO} \times \frac{C}{100} \times \frac{5683}{Cal.}$ Val. of fuel.

Where C is the percentage of carbon in the fuel, and the calorific value is expressed in calories per gramme of fuel. When hydrogen and methane are also present, one volume of hydrogen will give a heat loss equal to that from 0.86 volumes of carbon monoxide, this being the ratio of the calorific values; for methane the ratio is 2.8, so that the modified formula is:—% heat loss due to unburnt CO, H_2 and CH_4 $= \frac{CO+0.86H_2+2.8CH_4}{CO_2+CO+CH_4} \times \frac{C}{100} \times \frac{5683}{Cal.}$ Val. of fuel.

This supposes that net calorific values are used; for gross values the equation is % loss$= \frac{CO+H_2+3.1\ CH_4}{CO_2+CO+CH_4} \times \frac{C}{100} \times \frac{5683}{Cal.}$ Val. of fuel.

The percentage loss due to unburnt solid carbon, assuming a calorific value of 8143 cal. per gramme, will similarly be:—Fraction of total carbon unburnt $\times \frac{C}{100} \times \frac{8143}{Cal.}$ Val. of fuel.

One method of arriving at the fraction unburnt has already been described. The usual plan is to determine the unburnt carbon in an average sample of the ash from the furnace (dried at 105 deg. Cent.) by the loss in weight on incineration; then knowing the ash content of the coal, the fractional loss is easily computed. Suppose the coal contains y per cent. of ash, and suppose the "ash" from the furnace is found to consist of z per cent. of unburnt carbon and 100—z per cent. of true ash, then the loss of unburnt carbon per unit weight of coal is $\frac{yz}{100-z}$ and the percentage heat loss is $\frac{yz}{100-z} \times \frac{8143}{Cal.}$ Val. of fuel.

This method takes no account of unburnt carbon particles in the chimney gases, except in so far as they are accompanied by ash.

Regulation of the air supply.—In adjusting the air supply to a boiler-furnace, the aim will be to make the sum-total of the losses due to incomplete combustion and sensible heat as small as possible, provided the work of the furnace is not thereby impeded. It will be found that the presence of 0.1 or 0.2 per cent. of carbon monoxide in the flue gases, does not involve a serious loss of heat, and it would be a mistake to use a largely increased excess of air, simply to avoid a small loss of this character. On the other hand, 0.5 per cent. of carbon monoxide, or more, will generally mean that the air supply is below the optimum.

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*The figure 579.5 calories per gramme of water vapour is the latent heat at 15 deg. Cent. It is necessary to use this figure if the other calculations have been made in the manner described, because in calculating the sensible heat loss the whole of the flue gases have been supposed to be cooled to 15 deg. Cent.

As an example of the systematic determination of the optimum air supply for a boiler, some figures given by Grebel (Chaleur and Industrie, 1926, 7, 307) may be quoted:—

Excess air percentage.	25	75	125
% loss by sensible heat in flue gases ...	15	16·5	18
% loss by unburnt carbon	9	2	1·5
% loss by unburnt flue gases	1	0	0
Total heat loss percentage ...	25	18·5	19·5

From these results, it may be concluded that in this particular case a 75 p.c. excess of air is the proper proportion. This will apply only to the boiler used in the experiments and to the fuel and method of operation actually employed. Any change, enabling the optimum excess of air to be reduced, will be an improvement as far as fuel economy is concerned, although other disadvantages (e.g., increased cost) may offset the benefit obtained.

The most comprehensive series of determinations of the optimum air supply to boilers known to the writer, is that carried out by Bailey (see *Mechanical Engineering* for July, 1926). A large number of plants of each type were tested, and the average results for all plants, good, bad and indifferent, were those tabulated below:—

No. of plants tested.	Fuel burnt.	Method of firing.	Optimum excess of air, per cent.
27 ...	Wood	Various	61
294 ...	Coal	Chain-grate stokers, natural draught	55
265 ...	Coal	Over-feed stokers	53
155 ...	Coal	Hand-firing	53
401 ...	Coal	Chain-grate stokers, forced draught	49
1877 ...	Coal	Underfeed stokers, forced draught	45
135 ...	Coal	Pulverised fuel	28
307 ...	Oil	Steam atomisers	23
236 ...	Oil	Pressure atomisers	22
10 ...	Gas	Various	19

These figures will give some idea how far the restriction of the air supply can, advantageously, be carried in different circumstances; but a smaller air supply can be used in the best-designed plants of the various categories. Unless one is prepared, however, to work out carefully all the heat losses, the air supply used should be larger rather than smaller than the above; for, as may be seen from the example of Grebel's quoted above, the extra loss, due to using more than the optimum air supply, is small compared with the extra loss due to using less than the optimum amount.

According to Bailey, when too little air is used, the largest item in the loss by incomplete combustion is that due to unburnt gases when coal is used (Grebel's boiler appears to be an exception to this statement); with oil-firing, however, the loss of carbon in the gases (smoke and soot), is the decisive factor; the loss of carbon in the ashes is greatest with the chain-grate stoker, but, even here, is usually less than the loss by unburnt gases; with pulverised fuel firing the need for avoiding too high a temperature, with consequent damage to the brickwork of the combustion chamber, may be the factor which prevents the air supply from being still further reduced; this, however, will not apply in cases where the combustion chamber has water-cooled metallic walls.

Chapter 2.

DATA ON RELATION BETWEEN BOILER PLANT AND DESIGN AND COAL CLASSIFICATION.

By W. M. Miles, F.C.S., A.I.Mech.E.

Whilst improvements in boiler design and auxiliaries, in general, permit of increased output with economy, the efficiency of any steam generating unit is no greater than that of the furnace, consequently, much depends on the fuel used and the manner in which combustion is effected. For with unsuitable conditions or fuel in the furnace, no matter what type of boiler or stoker is used, it is impossible to obtain the best efficiency, until the necessary furnace conditions exist.

Arch design and furnace volume are of paramount importance for the economical burning of fuel, and combustion chambers can be designed to burn a good range of coals in a satisfactory manner, but where several grades of fuel are used and no two furnaces are alike, it is difficult to secure ideal conditions. This is especially the case in large undertakings, sometimes drawing their requirements from ten to thirty collieries, the coal supplied to any furnace being of varying quality necessitating rigid supervision to get the best out of it.

CLASSIFICATION OF FUEL.

Coal is by far the most important fuel used throughout the British Isles, and is likely to remain so for some considerable time to come, although semi-coke from low-temperature carbonisation processes will, in the future, be of considerable importance, either as a domestic fuel or for steam raising; this will not only permit of a large conservation of fuel and by-products, but will reduce to a minimum the pollution of the atmosphere with smoke and soot, for this class of fuel is practically smokeless, resembling coke, but containing just sufficient volatile hydrocarbons to enable it to burn more freely. Coke is used extensively in the manufacture of steel and, to a certain extent, either alone or mixed with coal for the generation of steam, but for large units and quick demands of steam, it leaves much to be desired.

Although a classification is desirable, nothing of a definite nature has so far materialised, and commercial misnomers are too often applied, with the result that bituminous coals are sometimes described as being equally useful for steam, gas, or industrial uses, hence there are no lines of demarkation.

Classification of coal should be based on the combustible content, to the exclusion of moisture and ash. For broad grouping, the volatile hydrocarbon content can, usually, be employed with satisfaction, but for further differentiation of each group, it serves no useful purpose.

In 1900, Seyler put forward his thesis of coal classification. This was based on certain defined limits of carbon and hydrogen, and of several attempts is, probably, the best, since it is possible to cut out such ambiguous terms as "dry," "fat," "hard," "half-fat," etc.

Classification of Coal (Seyler).

Class.	Hydrogen %.	Volatile Matter %.	Trade Name.
Anthracite	Under 4	Under 8	Anthracite.
Semi-anthracite or carbonaceous	4.0—4.5	8—16	Smokeless steam.
Semi or sub-bituminous	4.5—5.0	16—26	Bunker (short flame coal).
Normal bituminous	5.0—5.8	26—32	Gas, steam, etc.
Per bituminous	Above 5.8	Over 32	Large flame coal.

Anthracite. Anthracite, though not widely distributed, is a very valuable fuel, and is found, chiefly, in South Wales and to a certain extent in Scotland. The percentage of ash is usually lower than that of

bituminous coal, but it kindles slowly and with difficulty, commencing with a short yellow flame and gradually changing to a transparent faint blue, generally attributed to the absence of solid particles of carbon.

Semi-Anthracite. Semi-anthracite is not so hard or lustrous as true anthracite, and when newly fractured will soil the hands. It contains more volatile matter, hence it ignites more quickly and burns more readily, giving out intense heat. This class of fuel is particularly suited to marine requirements and is smokeless.

Semi - Bituminous. Semi-bituminous coals, sometimes called "Navigation," "Bunker," and "Smokeless" steam coals, represent the highest class for steam generating purposes. They are softer than the latter class and not so lustrous, although they are brighter than bituminous coal. Semi-bituminous coals contain more volatile hydrocarbons than the anthracite and burn much more readily, but as a class they resemble the anthracite more than the bituminous. They are, ordinarily, of high calorific value, free burning, and practically smokeless, but require plenty of draught.

Bituminous. Bituminous, or soft coals, as they are usually called, range in hardness from lignite to semi-bituminous, the harder varieties having the best heating values. The amount of volatile hydrocarbons present in the coal is the chief determining factor for its utility in practice; it governs the nature of combustion, determines its suitability for special industrial requirements, and the design of furnace and grate necessary for the efficient combustion of the various classes of coal. Bituminous coals, on the average, are brittle having a vitreous resinous or greasy lustre. There are two classes, usually designated as "Caking coals," and "Non-Caking," or "Free burning" coals. The former, like cannel, are very rich in hydrocarbons, and, in consequence, are much used for the manufacture of gas. Non-caking coals, although retaining their shape, do not fuse, burn more freely and are most useful for steam raising.

The conditions effecting the distillation of bituminous coals during combustion is a measure of the heat developed, whether efficient or otherwise, and the proportion of heat given up on the grate and in the combustion chamber, respectively, varies with the amount of volatile matter present.

For bituminous coals, the amount of heat derived from the volatile hydrocarbons may be taken as one-third of the total, but as the poorer grades are reached, containing increased amounts of impurities, the figure is nearer one-half. Constam and Schlapfer stated that the coal best suited for maximum temperature and efficiency were those containing, approximately, 20 per cent. of volatile matter, on the total combustible ratio. The majority of coal used for steam generating purposes contains considerably more than this percentage, and the high efficiencies obtained are only possible with mechanical stokers, under rigid control.

For local heating, and where limited combustion space is available, coals approaching the anthracitic class are usually employed, whilst for long flame bituminous coals ample combustion space is necessary. Hence, for steam raising, these considerations govern the ratio of grate area to volume of furnace, and the air necessary for combustion, both under and above the fuel bed, to get the best results out of any given coal. Whilst for steam raising, high calorific value is essential, other factors require equal consideration and depend, largely, on the amount of volatile combustible matter present. The amount of ash and moisture is also important, but this subject is elaborated later.

When large amounts of volatile matter are present, insufficient air above the grate would result in smoke and incomplete combustion, just as too much air would carry to waste useful heat. On the other hand, coals containing lower percentages of volatile matter would require a larger proportion of air to pass through the fuel bed from below, to effect the complete combustion of the remaining coke, after most of the volatile matter has been driven off.

The output of any steam generating unit is governed by the furnace temperature and the rate at which the fuel can be burned on the grate, or, in other words, for a given boiler output, a definite amount of heat must be delivered, per square foot of grate area, and anything below that amount will be insufficient to meet the steam demand. Naturally, for coals of varying heat contents the pounds of coal burned per square foot of grate will vary with the calorific value which, for 400,000 B.Th.U.'s per square foot of grate area per hour, would be, approximately, as follows :—

Calorific Value of Fuel, as Fired.	Lbs. of Coal per Square Foot of Grate Area.
10,000 B.Th.U.'s.	40.0
11,000 „	36.4
12,000 „	33.3
13,000 „	30.8

From which it will be apparent that "Lbs. of coal burned per square foot of grate area" is just such another ambiguous term, as "Lbs. of water evaporated per lb. of coal," and serves no useful purpose unless the calorific value of the fuel is stated.

THE EFFECT OF VARIATION IN SIZE.

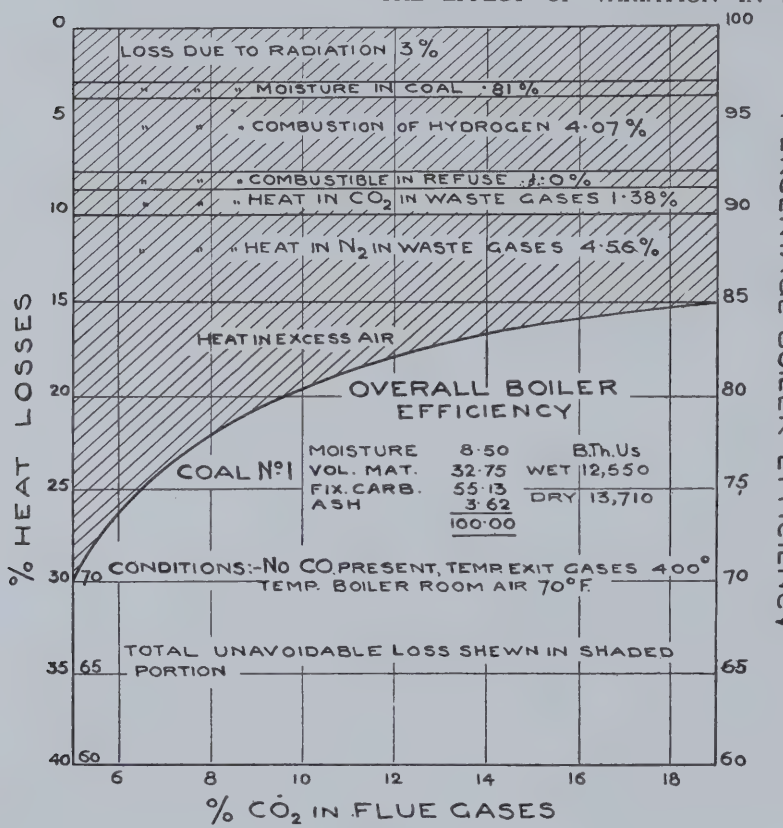

LOSS DUE TO RADIATION 3%
" " " MOISTURE IN COAL 8·1%
" " " COMBUSTION OF HYDROGEN 4·07%
" " " COMBUSTIBLE IN REFUSE 1·0%
" " " HEAT IN CO_2 IN WASTE GASES 1·38%
" " " HEAT IN N_2 IN WASTE GASES 4·56%
HEAT IN EXCESS AIR
OVERALL BOILER EFFICIENCY
COAL Nº1
MOISTURE 8·50
VOL. MAT. 32·75
FIX. CARB. 55·13
ASH 3·62
100·00
B.Th.Us
WET 12,550
DRY 13,710
CONDITIONS:-No CO PRESENT, TEMP EXIT GASES 400°
TEMP. BOILER ROOM AIR 70°F.
TOTAL UNAVOIDABLE LOSS SHEWN IN SHADED PORTION
% HEAT LOSSES
PERCENTAGE BOILER EFFICIENCY
% CO_2 IN FLUE GASES

FIG. 1.

Graded coal of standard size is much to be preferred to a mixed coal, for, generally speaking, the calorific value of coal as used for steam generating purposes decreases as the size diminishes, hence uniformity in size is of considerable importance.

Where chain grate stokers are fitted, excessive amounts of fine matter usually result in greater quantities of "riddlings" falling through the interstices of the grates, and not only necessitate more time for their removal, but have a deleterious effect on the coal. The effect of variation of size on samples of ordinary dry slack and washed nuts, is given on another page. It will be noticed that, although there is a distinct variation with the former, that of the latter is not so apparent.

Another effect of too much small matter, particularly in dry slacks, is the excessive amount of flue dust formed in the tube passages and flues, which not only reduces draught and wastes a certain amount of heat, but entails extra labour for its removal.

FLUE DUST FROM FIVE-DRUM STIRLING BOILER.

	Fixed Carbon %	Ash %	B.Th.U.'s.
Furnace (front bank)	4.70	95.3	680
Superheater	8.35	91.65	1,210
Middle Chamber	19.55	80.45	2,830
Back Chamber	23.22	76.78	3,371
Economiser Inlet	20.10	79.90	2,910
Economiser Outlet	22.55	77.45	3,270

It will be apparent, therefore, that different coals require different conditions for their efficient combustion, for after all the actual burning of coal is a compromise and means striking the happy medium between loss due to incomplete combustion, on the one hand, and waste of heat by excessive air on the other. The draught necessary for one coal may not suit another and, although the quantity of air required

Table I.—Analysis of the Different Sizes of a Yorkshire Dry Slack (as received).

No.	1.	2.	3.	4.	5.	6.
Retained by sieve.	1in.	½in.	¼in.	⅛in.	Fine.	Shale and Slate.
Ultimate Analysis.						
Moisture	8.50	8.50	8.33	8.35	8.50	4.50
Carbon	67.97	67.70	66.27	62.78	55.36	26.04
Hydrogen	4.73	4.58	4.40	4.17	3.62	2.64
Sulphur	1.81	1.73	1.65	1.57	1.34	2.19
Nitrogen	1.56	1.54	1.54	1.41	1.15	0.67
Oxygen	11.80	11.78	10.61	9.62	7.17	3.80
Ash	3.62	4.17	7.20	12.10	22.86	60.16
	100.00	100.00	100.00	100.00	100.00	100.00
Proximate Analyses.						
Moisture	8.50	8.50	8.33	8.35	8.50	4.50
Volatile Matter	32.75	32.16	30.71	29.56	26.35	16.49
Fixed Carbon	55.13	55.17	53.76	49.99	42.29	18.85
Ash	3.62	4.17	7.20	12.10	22.86	60.16
	100.00	100.00	100.00	100.00	100.00	100.00
Calorific value in B.Th.U.'s { As received	12,550	12,490	11,720	11,000	9,420	3,920
Calorific value in B.Th.U.'s { Dried at 220° F.	13,710	13,640	12,790	12,000	10,300	4,100
Products of Combustion.						
Carbon Dioxide, lbs. CO_2	2.4930	2.4820	2.4310	2.3020	2.0300	0.9550
Water, lbs. H_2O	0.5107	0.4972	0.4793	0.4588	0.4108	0.2826
Sulphur Dioxide, lbs. SO_2	0.0364	0.0346	0.0330	0.0314	0.0268	0.0438
Total Nitrogen, lbs. N_2	7.0189	6.9484	6.8138	6.4664	5.7286	2.9853
	10.0590	9.9622	9.7571	9.2586	8.1962	4.2667
Air Required, lbs.	9.0952	9.0039	8.8291	8.3796	7.4248	3.8683
Maximum CO_2 % Available	18.44	18.52	18.50	18.47	18.40	16.91

Table II.—Proximate Analyses of the Different Sizes of Yorkshire Washed Nuts (as received).

Retained by Sieve.	1in.	½in.	¼in.	⅛in.	Fine.	Slate.	Original Mixed Sample.
Per cent. Retained	13.0	28.8	28.8	18.6	10.8	...	...
Moisture	6.94	8.14	8.52	10.30	12.55	...	8.90
Volatile Matter	34.50	32.90	32.05	31.45	29.80	...	31.88
Fixed Carbon	54.32	52.50	50.79	48.89	46.63	...	52.27
Ash	4.24	6.46	8.64	9.36	11.02	...	6.95
	100.00	100.00	100.00	100.00	100.00	...	100.00
Calorific value in B.Th.U.'s { As received	12,840	12,380	12,130	11,720	11,360	...	12,250
Calorific value in B.Th.U.'s { Dried at 220° F.	13,800	13,480	13,250	13,060	12,990	...	13,450

to burn coal increases theoretically as the heating value, the actual amount required to burn coal economically is considerably greater, due to increased resistance offered by the smaller particles of coal to the passage of air.

The selection of coal, therefore, for given conditions depends on many considerations besides the heating value. The question of the cost of generating a given amount of steam being the ultimate criterion by which any coal-burning equipment can be judged, it follows that the coal with the lowest price, or that with the least impurities, after making prolonged tests and taking everything into consideration, may not be the most economical to use.

ARCH DESIGN AND FURNACE TEMPERATURE.

Furnace temperature limits the use of certain coals, for unless this is sufficiently high, it is impossible to distil off the volatile portion at the rate necessary to support combustion, and keep the bed of fuel lively. Hence, it sometimes happens that the coal passes the whole length of the grate like a large blanket without being burned. This may also happen with good quality coal, but too large in size, when the air passes through too freely and chills the arch, the temperature being insufficient to effect distillation. Too thin a fire, or an improperly designed arch would produce the same result.

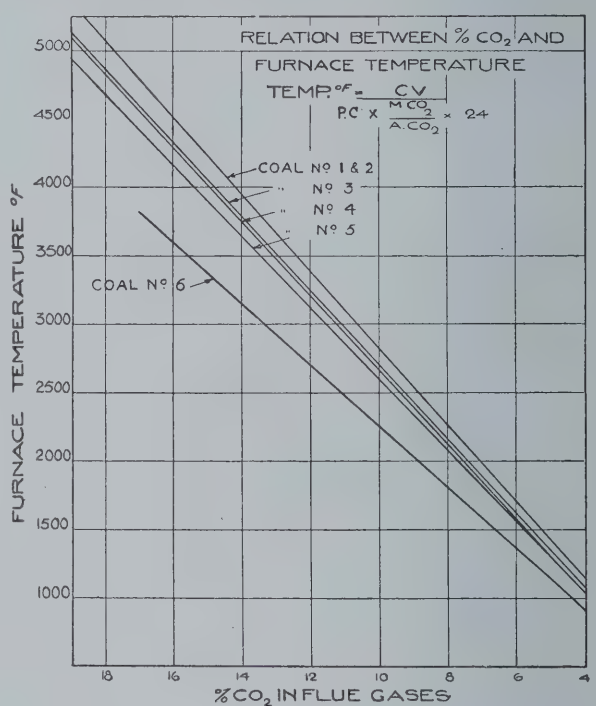


Fig. 2.

Theoretically, the height of the arch above the fuel bed should be adjustable to satisfy the requirements of the coal available, just as a boy would focus a lense between the sun and the piece of paper he wishes to ignite. Then again, the shape of an arch merits more consideration than is generally given to it. Arches when incandescent have vitrified surfaces, which act like mirrors, or the lenses of radiation pyrometers, but with a fixed focus; hence, either the coal must be adjusted, or the design altered to meet requirements. The ignition arch used in conjunction with chain grates or overfeed stokers is substantially a mirror, or heat reflector, receiving the heat from the rear and hotter parts of the fuel bed and refractory materials, and radiating it to the green coal entering, thus assisting distillation and ignition.

Resulting from this process of destructive distillation, are suspended particles of tarry matter and carbon which, insulated from a sufficient supply of oxygen by the products of combustion, pass into the combustion chamber proper, where a turbulent flow, or scrubbing action, set up within brings them into contact with the oxygen they require, and so completes the combustion.

The chief aim in efficient furnace design is to produce a turbulent flow; stratification of gases restricts the rapidity of combustion, and should be avoided by the introduction of suitable refractory baffles.

The effect of carbon dioxide (CO_2).

In practice, any variation required rests between grate speed and fire thickness, but the combustion of any fuel depends, primarily, on the amount of air with which it can be burned economically and efficiently, without introducing unnecessary excess, and as the temperature of the furnace increases as the percentage of CO_2 present increases, this latter is the chief criterion of furnace efficiency. Providing that the unavoidable losses are known, the percentage of CO_2 present in the flue gases is a direct indication of boiler efficiency, which may be seen in Fig. 1.

The furnace temperature can be conveniently observed by the use of an optical radiation pyrometer, but, if this is not available, may be approximated, provided the ultimate analysis and the actual amount of CO_2 are known, assuming a constant specific heat of the flue gases of .24 and neglecting radiation losses. *See Fig. 2, Coal No. 1.*

$$\text{Temp. } ^\circ\text{F.} = \frac{\text{C.V.}}{\text{P.C.} \times \frac{\text{M.CO}_2}{\text{A.CO}_2} \times .24}$$

Where — C.V. equals Calorific value of coal as received.
P.C. equals Lbs. gaseous products of combustion per lb. of coal (theoretical).
$M.CO_2$ equals Maximum CO_2 per cent. available.
$A.CO_2$ equals Actual CO_2 per cent.

Example :—From previous page.

C.V. equals 12,550 B.Th.U.'s. $M.CO_2$ equals 18.44 per cent.
P.C. equals 10.0590 lbs. $A.CO_2$ equals 11 per cent.

Then

$$\text{Furnace Temperature, deg. F.} = \frac{12{,}550}{10.0590 \times \frac{18.44}{11} \times .24}$$

Equals 3,100 deg. F.

COMBUSTION OF COAL.

The composition of the waste gases varies with the ultimate analysis of the coal, and the amount of heat discarded varies with the temperature, and proportion of flue gases present.

In the theoretical combustion of the matter employed, 12 parts by weight of carbon combine with 32 parts of oxygen, and form 44 parts of carbon dioxide. Hydrogen combines with 8 times its weight of oxygen and forms water, whilst sulphur combines with its own weight of oxygen and forms sulphur dioxide, the chemical actions being as follows :—

Carbon		Oxygen		Carbon Dioxide
C	+	O_2	=	CO_2
12		32		44
Hydrogen		Oxygen		Water
$2H_2$	+	O_2	=	$2H_2O$
4		32		36
Sulphur		Oxygen		Sulphur Dioxide
S	+	O_2	=	SO_2
32		32		64

						Heat Developed in B.Th.U.'s.
Therefore 1 lb. of carbon	will form	$1 \times \frac{44}{12}$	equals	3.667 lbs.	CO_2 +	14,600
1 lb. of hydrogen	will form	1×9	equals	9.00 lbs.	H_2O +	62,000
1 lb. of sulphur	will form	$1 \times \frac{64}{32}$	equals	2.00 lbs.	SO_2 +	4,000

PRODUCTS OF COMBUSTION FROM 1LB. OF COAL.

Analysis.	%	Weight in 1lb. Coal	Gaseous Products				Lbs. Ash.	Lbs. Oxygen.	Air used Lbs.
			lbs. CO_2	lbs. H_2O	lbs. SO_2	lbs. N_2			
Carbon	67.97	.6797	2.4930					1.8133	
Hydrogen ..	4.73	.0473		.4257				.3784	
Sulphur	1.82	.0182			.0364			.0182	
Nitrogen	1.56	.0156				.0156 in coal		—	9.0952
						7.0033 in air		—	
Moisture	8.50	.0850		.0850				—	
Oxygen	11.80	.1180						.1180	
Ash	3.62	.0362					.0362	—	
	100.00	1.0000	2.4930	.5107	.0364	7.0189	.0362	2.0919	

In arriving at these figures, the amount of oxygen present must be taken into consideration, and deducted from the amount of oxygen required and introduced by way of draught. Air contains approximately 23 per cent. of oxygen and 77 per cent. nitrogen by weight hence, in the example given 2.2099 lbs. of oxygen were required, which, after deducting .1180 lbs. present in the coal, leaves 2.0919 lbs., therefore, $2.0919 \times \frac{100}{23}$ or 9.0952 lbs. of air were required, bringing with it 7.0033 lbs. of nitrogen, the total amount of nitrogen in the theoretical waste gases now being .0156 lbs. plus 7.0033 = 7.0189 lbs.

In the coal under review, the amount of carbon dioxide formed from .6797 lbs. of carbon was 2.4930 lbs., and the nitrogen inadvertently added, together with that present in the coal, was 7.0189 lbs., hence, omitting sulphur compounds, which are negligible, CO_2 and N_2 preponderate in dry chimney gases, and their theoretical volumes may be calculated as follows :—

Proportion by volume equals

$$\frac{\text{lbs. } CO_2}{\text{Molecular Weight}} : \frac{\text{lbs. } N_2}{\text{Molecular Weight}} = \frac{2.4930}{44} : \frac{7.0189}{28}$$

$$\text{or } \frac{7.0189 \times 44}{2.4930 \times 28} = 4.425.$$

Ratio of N_2 to CO_2 = 4.425 to 1 = 5.425 total.

Hence, in 100 volumes the percentage of CO_2 available equals

$$\frac{100 \times 1}{5.425} = 18.44 \text{ per cent. } CO_2$$

or

$$\frac{100 \times 4.425}{5.425} = 81.56 \text{ per cent. } N_2$$

The amount of CO_2 present in the flue gases is a measure of the degree of combustion realised in the furnace, thus anything less than the theoretical amount signifies excess air, the loss due to same varying with the amount and temperature at which it is discarded.

To determine the volume and weight of this excess, we will assume that the temperature of the boiler room is 70 deg. F., the gases escape at a temperature of 400 deg. F., the CO_2 present being 11.0 per cent. Therefore, using the theoretical percentage CO_2 obtained above, 100 volumes become :—

$$\text{New volume} = \frac{100 \times 18.44}{11} = 167.6 \text{ volumes.}$$

Hence, there are 67.6 volumes of excess air present.

Specific Gravity of Gases at N.T.P. (32 Deg. F. at 29.92ins. Hg.)

	Specific Gravity Air = 1	Cubic Feet per Lb. of Gas.
Air	1.0000	12.39
Nitrogen — (N_2)	0.9673	12.81
Carbon Dioxide — (CO_2)	1.5289	8.104
Carbon Monoxide — (CO)	0.9672	12.81
Sulphur Dioxide — (SO_2)	2.2640	5.473

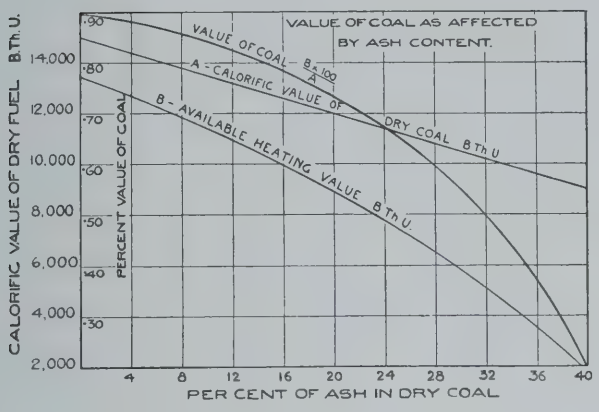


Fig. 3.

Composition of original 100 volumes.

	Cubic ft. N.T.P.
2.4930 lbs. of CO_2 = 2.4930 × 8.104 =	20.20
7.0189 lbs. of N_2 = 7.0189 × 12.81 =	89.91
Total	110.11

Therefore 100 volumes equals 110.11 cubic feet.

67.6 volumes equals $\frac{110.11 \times 67.6}{100}$ = 74.43 cubic feet.

Volume of excess air = 74.43 cubic feet.

Hence the 67.6 volumes of excess air are 74.43 cubic feet weighing $\frac{74.43}{12.39}$

= 6.007 lbs. excess air.

Weight of excess air = 6.007 lbs.

Air theoretically required = 9.0952 lbs.

Hence $\frac{6.007 \times 100}{9.0952}$ = 66.04% by weight.

Composition of Flue Gases per Lb. of Coal.

Calculated from Actual % CO_2 and Ultimate Analysis.

% CO_2	Volume of Mixture. Cubic feet. (a)	Volume of Excess Air. Cubic feet. (b)	Excess Air. Lbs. (c)	Excess Air. % (d)
18.44	110.1	0	0	0
17	119.4	9.3	.75	8.25
16	126.9	16.8	1.36	14.90
15	135.3	25.2	2.03	22.37
14	145.0	34.9	2.82	30.96
13	156.2	46.1	3.72	40.91
12	169.1	59.0	4.76	52.36
11	184.5	74.4	6.00	66.03
10	203.0	92.9	7.50	82.43
9	225.6	115.5	9.32	102.5
8	253.7	143.6	11.59	127.5
7	290.0	179.9	14.52	159.7
6	338.3	228.2	18.42	202.5
5	406.0	295.9	23.88	262.5
	$a = \frac{110.1 \times 18.44}{CO_2}$	$b = a - 110.1$	$c = \frac{b}{12.39}$	$d = \frac{c \times 100}{9.0952}$

Loss due to excess air, CO_2, and N_2 in waste flue gases.

Having above determined the weights of CO_2, N_2, and excess air in the flue gases with an actual CO_2 of 11 per cent., it is desired to know the loss in heat units and percentage on the coal as fired, the temperature of the gases being 400 deg. F. and the air 70 deg. F.

MEAN SPECIFIC HEATS AT CONSTANT PRESSURE FOR TEMPERATURES USUALLY ENCOUNTERED.

Oxygen O_2	.217	Dry Flue Gases	.24 (average)
Nitrogen N_2	.247	Water	1.00
Hydrogen H_2	3.420	Water vapour	.47
Air	.240		
Carbon Monoxide CO	.243		
Carbon Dioxide CO_2	.210		

		Loss in B.Th.U.'s.	% Loss on 12,550 B.Th.U.'s Coal.
Therefore, 2.4930 lb. $CO_2 \times .210 \times (400-70)$	=	172.8	1.38
7.0189 lb. $N_2 \times .247 \times (400-70)$	=	572.2	4.56
6.007 lb. Air $\times .240 \times (400-70)$	=	475.7	3.79
Total Loss in Dry Chimney Gases		1220.7	9.73

Hydrogen in the coal.

It has been pointed out that 1 lb. of hydrogen combines with 8 lbs. of oxygen to form 9 lbs. of water, and if the resulting water vapour is condensed it will give up 62,000 B.Th.U.'s, thus, other things being equal, the greater the % H_2, the greater will be the heating value. When the calorific value of coal is determined in the bomb calorimeter, the latent heat of evaporation of the water formed is credited to the coal, but, in practice, this heat, together with further heat required for superheating or raising the temperature from 212 deg. F. to that of the exhaust gases, is wasted.

Hence in making a true heat balance this heat must be taken into account.

LOSS DUE TO HYDROGEN.

B.Th.U.'s loss due to Hydrogen $= 9H_2 (212-t+970.7+.47 (T-212))$

where H = Hydrogen in 1 lb. of coal as received.

t = Temperature of coal as received, deg. F.

T = Flue Gas temperature, deg. F.

This in the case of Coal No. 1—Flue gas 400, Air 70—

$= 9 \times .0473 (212-70+970.7+.47 (400-212))$

$= .4257 (142+970.7+88.36)$

= 511.3 B.Th.U.'s, or 4.07% Loss.

Loss due to carbon monoxide.

Whilst the loss due to the presence of this gas is ordinarily small, it may assume large proportions with too thick fires and shortage of air.

When 1 lb. carbon is burnt to CO_2 14,600 B.Th.U.s' are realised.

Do. do. CO 4,450 do. do.

Hence, out of incomplete combustion 10,150 do. are wasted.

Loss to Carbon Monoxide may be determined as follows :—

$$C\ (10{,}150)\ \frac{CO}{CO_2+C} = \text{B.Th.U.'s loss on coal.}$$

Where CO and CO_2 are, respectively, the percentages by volume of these gases, and C the percentage of carbon obtained from the ultimate analysis.

MOISTURE IN COAL.

The presence of moisture in coal, like ash, must be regarded as dead loss. It may be present as "Inherent moisture" originally combined with the coal as mined, or "Free moisture" introduced by adverse climatic conditions, washing processes, etc. Generally speaking, moisture reduces the available boiler efficiency more than an equivalent amount of well burnt ash.

In the better grades of coal, where the percentage varies between 4 per cent. and 6 per cent., it is seldom a commercial proposition to effect any reduction, but with excessive amounts, especially in washed fuels, moisture is an expensive diluent and should be avoided as much as possible, for not only has it to be paid for and transported at fuel rates, but an additional loss occurs in the combustion of the coal, which approximates 1 per cent. for each 10 per cent. moisture present.

The tendency to rid lower-grade fuel of its impurities, primarily ash, by the wet-washing process, has introduced a new source of excessive moisture, figures of 20 per cent. not being uncommon with the smaller grades, which may be traced to insufficient time for drainage at the colliery. The increase should not be more than 1 per cent. for large grades, and 3 per cent. for the smaller grades of coal.

Considerable success has attended experiments with the dry washing process which should not only produce a desirable fuel of practically constant composition, but reduce to a minimum the loss due to excessive moisture and ash.

External corrosion of metal in the cooler parts of the system is often traced to excessive moisture in the coal, for once deposited, it has great affinity for gaseous sulphur compounds from the products of combustion which form sulphuric or sulphurous acids, both of which promote chemical action on the tubes, particularly those of cast-iron economisers.

Loss Due to Moisture.

This may be estimated as follows :—

$$\text{B.Th.U.'s loss} = M\ (212 - t + 970.7 + .47\ (T - 212))$$

Where M = lb. of moisture per lb. of coal
t = temperature of coal as fired, deg. F.
T = temperature of flue gases, deg. F.

For example, the total amount of water in 1 lb. of coal, No. 1, amounts to .085 lb., therefore, the gases being 400 deg. F. and coal 70 deg. F.,

$$\text{Loss equals } .085\ ((212-70)+970.7+.47\ (400-212))$$
$$= .085 \times (142+970.7+88.36)$$
$$= 102.1 \text{ B.Th.U.'s or } .814\% \text{ loss on } 12{,}550 \text{ B.Th.U. coal.}$$

Wetting of coal.

Trouble is sometimes experienced with dry slacks containing excessive amounts of small matter, due to the large amount of riddlings formed and in such cases wetting the coal may be beneficial. When this is necessary it is best to wet the coal, not in the hoppers unless it is well mixed, but as it is being dumped into the bunkers. Where conveyors are used, this process is conveniently carried out as the coal passes along to its destination. By this means, the wetted coal gravitates through the bunkers and chute, ultimately reaching the grate well mixed; water should only be used whilst coal is passing, avoiding excessive amounts.

Various claims have been made that better steaming conditions have resulted from this procedure, but it must not be overlooked that, any water added has to be evaporated at the expense of some of the heat in the coal, and that increased economy is only obtained when this loss is more than neutralised, by the increased economy obtained with better combustion on a more even fire grate, permitting higher CO_2, due to less excess air being used.

Another factor in favour of the wetting of coal to give better steaming conditions is the radiation constant of the products of combustion. The radiation from a mass of gas depends largely upon the CO_2 and H_2O contents, and the radiation constant for H_2O is considerably above the radiation constant for CO_2. With dry anthracite the rate of heat transfer by radiation is, therefore, less than with dry bituminous coal, and the difference is still greater with wetted bituminous coal, up to a point; therefore, it is certainly advantageous to have H_2O in the flue gases.

With pulverised fuel firing, where so much radiant heat absorbing surface is located in the furnace, this factor assumes considerable importance.

The effect of sulphur.

The sulphur found in coal probably has its origin in the plant life from which the coal was formed, but may also occur as pyrites, basic sulphates, or combined with organic substances.

Sulphur is objectionable for most purposes; with steam raising 1 lb. in combustion with oxygen only gives up 4,000 B.Th.U.'s, whereas carbon gives up 14,600 B.Th.U.'s and hydrogen 62,000 B.Th.U.'s, and, in addition to its lower heating value, the sulphurous compounds are objectionable because of their corrosive effect in the presence of water vapour on the cooler steel work, in general.

The sulphur in coal is largely affected by the amount of impurities introduced in mining, and a high percentage, not infrequently, corresponds with much iron in the ash due to its presence originally as pyrites, hence, it may indicate an ash with a tendency to clinker.

Spontaneous combustion has also been associated with sulphur, especially in the presence of much moisture. Probably, however, it is not due to this alone, but to the effect of the extremes of temperature and height of coal.

EFFECTS OF ASH IN COAL.

Ash, as found in coal, may be considered as coming from two sources:—

1. From matter present in the original vegetable material; and
2. Substances encased with the coal during formation, being chiefly clay, shale and sand. Another source for additional impurities is in mining, which unless screening and picking is carried out, may assume large proportions.

Fixed ash in coal is, essentially, Aluminium Silicate (Al_2O_3 $2SiO_2$), together with basic oxides, such as calcium oxide (CaO) magnesium oxide (MgO) ferric oxide (Fe_2O_3) and traces of sulphates, carbonates and phosphates, the colour of the true ash varying according to the amount of ferruginous matter present, from nearly white to a dark red.

Like moisture, ash is an expensive impurity and the effects of varying quality and quantity are far reaching and even with the best combustion, loss is entailed.

Generally speaking, its effect on heating value and combustion may be set out as follows:—

1. The heating value of coal decreases as the percentage of ash increases.
2. Loss due to combustible matter in the ash, which has a tendency to increase as the percentage.
3. The amount of heat discarded with the ash when dumping is carried out, increases, proportionately, to the amount of ash formed.
4. The prevention of a free passage of air through the fuel bed due to the formation of clinker, the degree of clinkering depending on the softening point and amount of ash; the quantity of encased unconsumed carbon in the boiler refuse also varies with these factors.
5. The amount of air, theoretically, required for combustion decreases as the percentage ash increases. In practice, however, it actually increases, excessive draught, introducing large amounts of air being necessary to effect anything like reasonable combustion, hence, the higher the ash content the greater will be the loss due to excess air.

Whilst depressions in combustion arches and side walls are, principally, due to scouring and flame propagation, lifting of fine coal and the degree of vitrification of the refractory material, deterioration is greatly accelerated when small particles of low fusion point ash deposit and act as a flux.

Various authorities have investigated the clinkering and softening properties of ash, but whilst they have found it difficult to correlate these with the chemical composition, it has been proved that the nearer the composition of the ash is to the true silicate of alumina ($Al_2O_32SiO_2$), the more infusible will it become, and that, on substitution of the alumina with other bases, particularly iron oxide (Fe_2O_3), the more fusible it will become, due to the formation of mixed, or double, silicates of lower softening points. The variation of clinkering properties has been attributed to sulphur content, but it is in the combustion of the coal in which the sulphur may be in various forms that the trouble originates; this basis is therefore unreliable. In any case, trouble due to softening of ash and amount of clinker formed will vary with the temperature of the fuel bed, and the amount of excess air admitted to the furnace, for, usually, it is only when high CO_2% is experienced that it occurs. The softening point of ash may be determined in the laboratory in a suitable gas, or electric furnace, but whilst this furnishes useful information, probably the only reliable basis for detecting objectionable properties, is during the actual burning of the coal.

Loss due to unburnt fuel in ash may be obtained by the formula:—

$$\text{B.Th.U.'s} = \frac{C \times A}{100 - C} \times 146$$

where C = % combustible in refuse.
A = % ash in coal as fired.

For example: Assume the ash on the coal to be 12 per cent. and the amount of combustible in the refuse, 15 per cent.

$$\text{Then } \frac{15 \times 12}{100 - 15} \times 146 = 309.6 \text{ B.Th.U.'s.}$$

Exclusive of pulverised fuel systems of firing, when the percentage of ash reaches excessive figures, the loss in heating value entailed is extraordinary and approximates 2 per cent. for each 1 per cent. increase of ash in the coal, which may be seen from Fig. 3.

In the curves given, allowances have been made for the following:—

(a) Variation and increase of ash content.

(b) Variation of combustible matter in dumped ash and sensible heat discarded with same at 1,000 deg. F.

(c) Variation in quality and grade of fuel, loss due to excess air, and loss due to moisture and combustion of hydrogen, these being deduced to a final temperature of 350 deg. F.

CONCLUSION.

It will be apparent from the foregoing, that coal is anything but a fuel of fixed value and although systematic analysis will detect and exclude those elements least desirable from an economic standpoint, the real loss encountered is that during combustion, particularly with the ash and loss due to excess air in the waste chimney gases; in other words, it is not a question of what is in the coal, but how much can be got out of it.

Cognisant of this, attempts to reduce these losses within reasonable limits have been attempted, both in automatic control and unit and complete systems for burning coal in pulverised form, and it is with the latter method that more economy and higher efficiencies are possible from a wide range of coals, to say nothing of a great conservation of energy that could be effected by burning cheap, and otherwise useless, fuels.

Broadly speaking, the pulverising of coal is the changing of a variable commodity to one more stable, not as regards its inert and useless content, but the remainder which in this finely divided form, permits of controllable combustion without the same magnitude of loss.

With pulverised fuel systems, loss due to ash, with most fuels, varies from .4 per cent. to 1.0 per cent., whereas, with mechanical stokers the figure is something like 1 to 3 per cent., according to the amount of ash and combustible discarded with same.

Radiation loss, with ordinary methods of firing varies from 2.5 to 5 per cent., but in larger combustion chambers using pulverised fuel, the maximum temperature occurs in the middle of the furnace, hence the walls, which are usually fitted with absorbing elements connected to the boiler circulating system, are, comparatively, cool, and the loss entailed is only of the order of 1.5 to 2.0 per cent. Loss due to excess air, also, is considerably reduced, for whereas with mechanical stokers it is seldom possible to run, for any length of time with more than 12 to 13 per cent. CO_2 without ruining the refractory material, 15 to 16 per cent. CO_2 may be regarded as a fair average for pulverised fuel. For very large units and capital stations running at high load factor, this method of burning coal should be most economical.

Chapter 3.

ECONOMIC ASPECTS OF HIGH PRESSURES AND TEMPERATURES.

By H. L. Guy and D. M. Smith, B.Sc.

It is the purpose of this chapter to consider, not only how the steam pressure, steam temperature and vacuum affect the efficiency of steam power plant operation, but, also, how the introduction of, what is known as, regenerative feed heating and resuperheating react on the coal consumption.

Further, since the engineer's interest in such matters, frequently resolves itself into finding a solution of the problem of obtaining the maximum return in electrical energy, from the minimum expenditure in effort, assessed on a gold basis, some attention will be paid to the method which should be adopted, to select the appropriate condition from this point of view.

The various parts of the plants whose collective efficiency is to be considered, are illustrated in Fig. 1. Following the steam circuit from the drum of the boiler proper, the steam passes first, through the superheater, now almost invariably incorporated in the boiler itself, and then, on to the steam chest at the inlet end of the turbine.

If a "Resuperheater" is incorporated in the system, the steam will be taken out of the turbine, after the steam has performed a certain amount of work, and passed through this resuperheater, where its temperature can be increased.

The resuperheater is, usually, incorporated in a special boiler, one of which may be installed for each two or three normal boilers, the resuperheater being designed to deal with the steam generated by the whole group of three or four boilers.

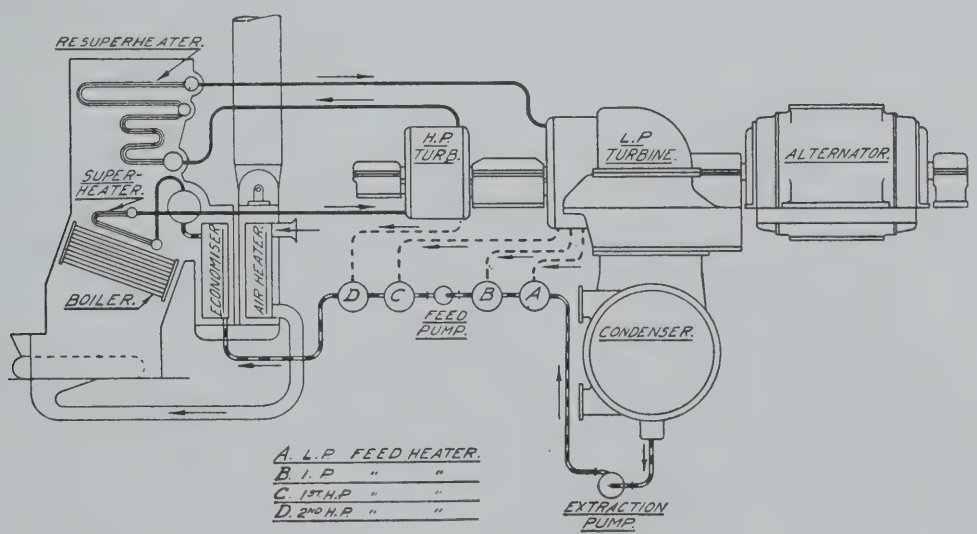


Fig. 1.—*Type of Installation considered.*

In the resuperheater, the steam temperature may be once again raised to the initial temperature at which it left the superheater, or, of course, to any other temperature. It is, however, scarcely justifiable to lay down a plant with a resuperheater temperature higher than the initial temperature, nor does there appear to be any very sound reason for adopting a lower temperature leaving the resuperheater, than that leaving the initial superheater itself, if the resuperheating is done by heat taken from the flue gases.

Proposals have been made for resuperheating by live steam. The thermal advantage of such a system is small, but the mechanical advantage of obtaining dryer steam, in the exhaust end of the turbine, may, in certain cases, justify its use.

Continuing the route of the steam on its return to the turbine, it completes its expansion and is in the main, finally condensed in the condenser.

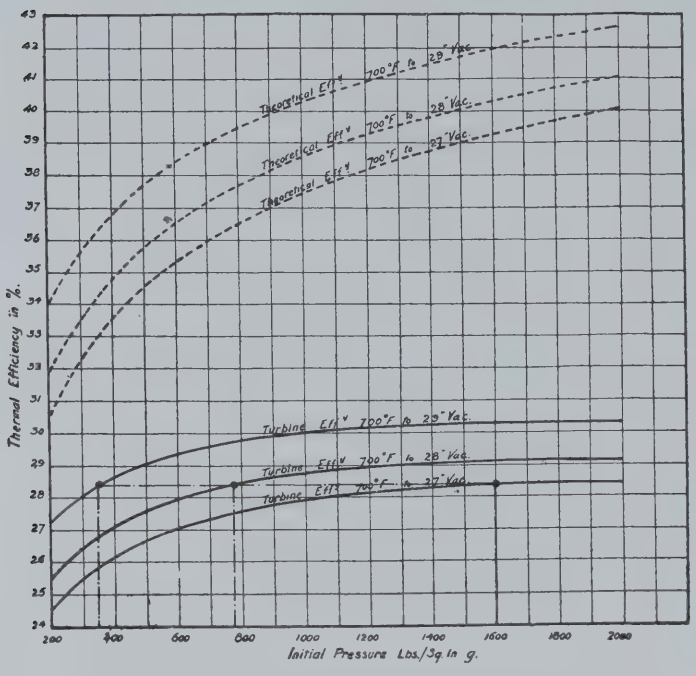

Theoretical Effy 700°F to 29" Vac.
Theoretical Effy 700°F to 28" Vac.
Theoretical Effy 700°F to 27" Vac.
Turbine Effy 700°F to 29" Vac.
Turbine Effy 700°F to 28" Vac.
Turbine Effy 700°F to 27" Vac.
Thermal Efficiency in %.
Initial Pressure Lbs./Sq. In. g.

FIG. 2.—*Thermal Efficiencies, 700° F. to 27ins., 28ins. and 29ins. Vacuum.*

The water of condensation is extracted from the condenser by the extraction pump, and passed through a succession of feed heaters, in which its temperature is successively raised by steam extracted from the main turbine, from points in the expansion at successively increasing pressures. This group of feed heaters forms the "Regenerative feed heaters."

The number of feed heaters, which a system should include, depends on the size of the plant, the relative importance of fuel economy and installation cost, and whether the boiler is equipped with economisers, air preheaters or both.

As a guide to what would be accounted good average practice, at the time of writing a regenerative feed heater system for a turbo set of, or above, 20,000 kw. capacity, would include three main feed heaters for steam pressures of 350 lbs., per sq. in., or higher, if the boiler plant includes economisers and feed heaters, while two feed heaters would be adopted if the air heater is omitted.

Where the machine load factor, price of fuel and price of plant, are all high, and justify elaboration above the average, the number of main feed heaters may, in each case, be increased to four and three, respectively. As the size of plant increases, so will the desirable number of feed heaters increase.

In general, the boiler feed pump is placed before the feed heater in the series, where the steam pressure is at, or above, atmospheric pressure.

Leaving the regenerative feed heater, the feed water enters the economiser, where its temperature will be raised as nearly as operating, or design, conditions will allow, to the saturation temperature of the steam in the boiler, before it leaves the economiser and enters the boiler. The modern tendency is all in the direction of reducing the difference between these two temperatures.

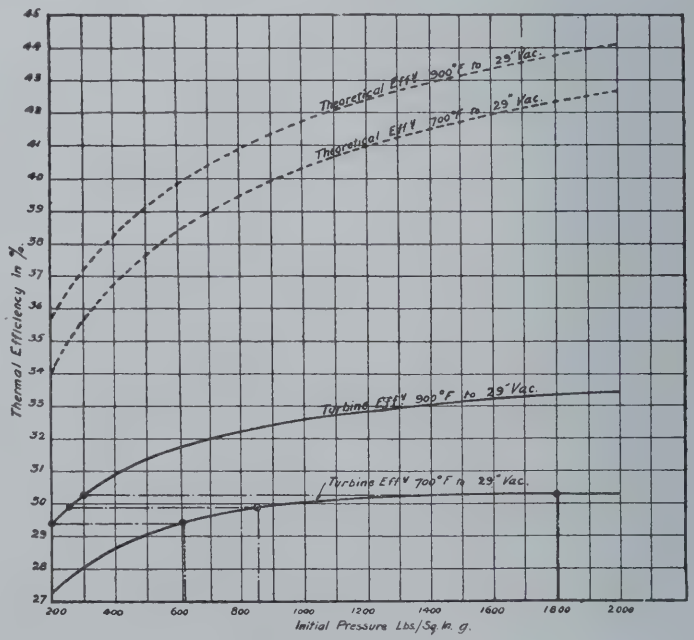

Theoretical Effy 900°F to 29" Vac.
Theoretical Effy 700°F to 29" Vac.
Turbine Effy 900°F to 29" Vac.
Turbine Effy 700°F to 29" Vac.
Thermal Efficiency in %.
Initial Pressure Lbs./Sq. In. g.

FIG. 3.—*Thermal Efficiencies 900° F. to 29ins. Vacuum.*

As the introduction of regenerative feed heaters, necessarily, resulted in increase of the temperature of the feed entering the economiser, and, therefore, of the flue gases leaving it, air preheaters are being

increasingly adopted, to reduce the flue gas temperature after the economiser by heating up the air necessary for combustion before it reaches the furnace.

The simplest method of assessing the thermal possibilities of the various elements of the plant as a whole, as affected by the various sets of steam conditions, lies in considering each modification separately, and making use of the fact that the gains arrived at separately are, approximately, directly additive, when the modifications are employed in combination.

Consider first the possible thermal efficiences of simple high pressure condensing turbines, without regenerative feed heating or resuperheating.

The upper series of curves, shown in dotted lines in Fig. 2, gives the ideal thermal efficiences for the steam condition stated, obtained by dividing the work which can be secured from an ideal (imaginary) engine working on the Rankine cycle, by the total heat which must be supplied to the steam.

The probable thermal efficiencies which can be expected in the average case are given in the full-line curves; the difference between the two sets represents the losses and gains which result from the effect

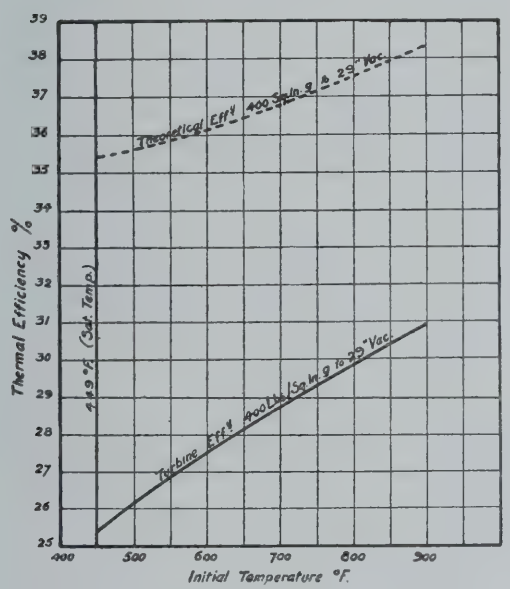

Thermal Efficiency %
Initial Temperature °F.
Theoretical Effy 400 Lbs/Sq.In g to 29" Vac.
Turbine Effy 400 Lbs/Sq.In g to 29" Vac.
419 °F. (Sat. Temp.)

FIG. 4.—*Thermal Efficiences, 400 lbs./sq. in. g. to 29" Vac.*

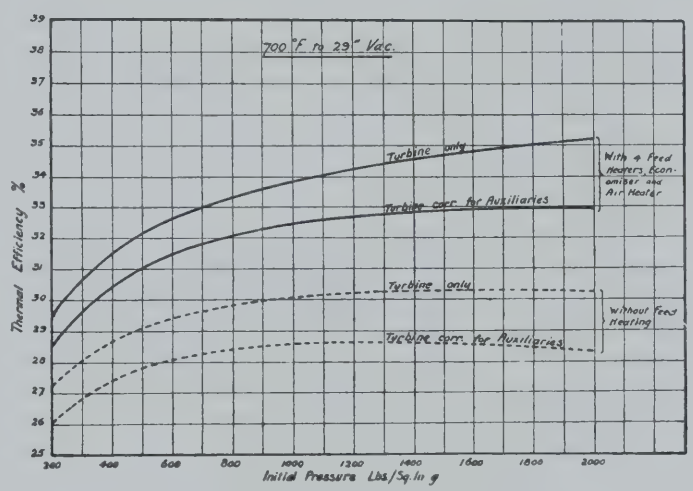

700 °F to 29" Vac.
Thermal Efficiency %
Initial Pressure Lbs/Sq.In g
Turbine only
Turbine corr. for Auxiliaries
With 4 Feed Heaters, Economiser and Air Heater
Without Feed Heating

FIG. 5.—*Effect of Auxiliaries on Thermal Efficiency.*

of "Wetness loss" and "Reheat factor," and the many internal losses of the turbine—some known, some unknown—which are affected by steam pressure, temperature and vacuum.* Throughout this series of curves, the initial steam temperature has been assumed constant at 700° F. at the turbine stop valve.

In Fig. 3, similar curves have been plotted for initial steam temperatures of 700° F. and 900° F., for various pressures and with a constant vacuum of 29ins.

Fig. 4 shows the influence of initial steam temperature on thermal efficiency of the turbine, for constant steam pressure and vacuum.

From Figs. 2, 3 and 4, the following deductions may be made, bearing on the relative thermal returns obtained by changes in initial pressure, vacuum and initial temperature, the particular cases considered being indicated by chain dotted lines:

(*a*) With a constant initial steam temperature of 700° F., it would be necessary to increase the initial steam pressure from 350 lbs./sq. in. to 775 lbs./sq. in., to obtain the same thermal efficiency on the turbine alone, if the vacuum is changed from 29ins. to 28ins. Again, if the vacuum is changed from 29ins. to 27ins., with the initial temperature and with the thermal efficiency of the turbine

* For details of these and the auxiliary machinery losses see "The Economic Value of Increased Steam Pressure," Proc.I.Mech.E., Feb. 1927, p. 99, by H. L. Guy, from which Figs. 1, 6 and 8 have been taken.

kept constant by raising the pressure, the initial steam pressure must be increased from 350 lbs./sq. in. to 1,600 lbs./sq. in.

(*b*) With a constant vacuum of 29ins., the gain in thermal efficiency of the turbine, which results from an increase in initial temperature of, from 700° F. to 900° F., is equal to the gain in thermal efficiency which results from an increase in initial pressure, covered by the step from 200 lbs./sq. in. to 610 lbs./sq. in., or, from 250 lbs./sq. in. to 850 lbs./sq. in., or, from 300 lbs./sq. in. to 1,800 lbs./sq. in.

It is desirable, in view of these comparisons, to consider how far choice in the selection of the three steam conditions involved, is free in any particular case.

The vacuum adopted will be determined by the conditions of site, depending, in the main, on the quantity, quality and temperature of the water available as cooling water for the condenser, coupled with inevitable economic considerations, involving the probable machine load factors, cost of plant and cost of fuel. In cases of very restricted water supply, when cooling towers become necessary, the vacuum will be determined, in the main, by the mean air temperature and humidity.

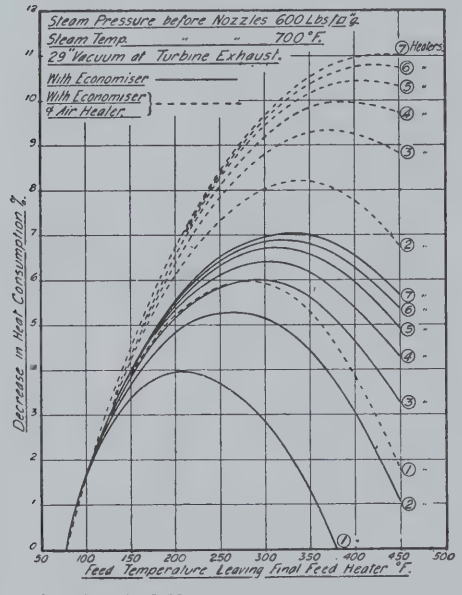

Steam Pressure before Nozzles 600 Lbs/Sq.
Steam Temp. " " 700° F.
29" Vacuum at Turbine Exhaust.
With Economiser
With Economiser & Air Heater
Heaters
Decrease in Heat Consumption %
Feed Temperature Leaving Final Feed Heater °F.

FIG. 6.—*Feed Heating at 600 lbs./sq. in. g.*

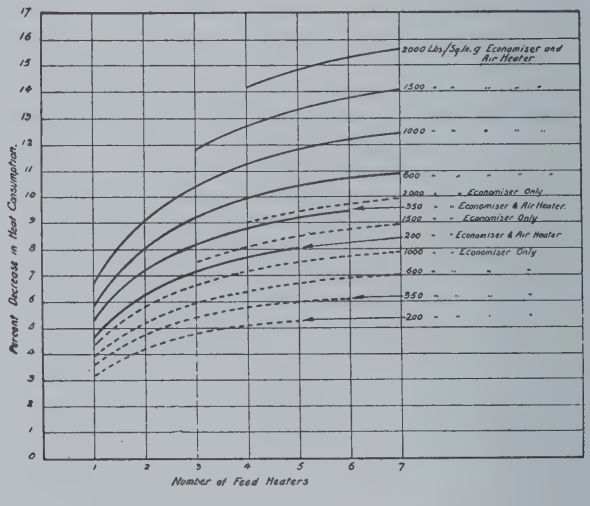

2000 Lbs/Sq.In.g Economiser and Air Heater
1500 " " " "
1000 " " " "
600 " " " "
Economiser Only
Economiser & Air Heater
Economiser Only
Economiser & Air Heater
Economiser Only
600 " " "
350 " " "
200 " " "
Percent Decrease in Heat Consumption
Number of Feed Heaters

FIG. 7.—*Maximum Gains from Feed Heating.*

In contrast with this, the choice of both initial steam temperature and pressure is limited by serious additional considerations of quality of materials available, and character of design of the plant. It can, however, be, generally, stated that the initial steam temperature which should be taken, is the highest which can be adopted with safety, and that the steam pressure which should be adopted is the highest which can be, economically, justified. In other words, at the present time, the choice of temperature will be limited, chiefly, by metallurgical and design considerations, whereas the choice of pressure will mainly be limited by economic and design considerations, while vacuum will be determined by site conditions.

So far, the influence of steam conditions on the turbine alone, has been considered. In order to assess the probable gains with higher pressure, on the plant as a whole, the influence of pressure on the power taken by the condenser pumps, the boiler fans, stoker or pulverisers, and feed pumps, must be taken into account.

Fig. 5 continues the basic case we have been considering, and gives, in the dotted curves, the thermal efficiency to be expected from the steam turbine, with and without correction, for the auxiliaries just named, for various constant pressures, with an initial temperature of 700° F., and with a vacuum of 29ins. The full-line curves give the thermal efficiency of the turbine, with and without the auxiliaries mentioned, if a four stage regenerative feed heating system is added. It is notable that, whereas the thermal

efficiencies for the turbines, without feed heaters, reach a well-defined maximum at 1,300 lbs./sq. in., the efficiency of the turbine with four stage feed heating progressively increases with pressure.

It is useful to note the steps in initial pressure, necessary to secure equal progressive steps in efficiency for the turbine, plus four stage feed heating, as given in the following table extracted from the paper on "The Economic Value of Increased Steam Pressure" already referred to.

Increments of Pressure for 3% Thermal Gain.

Accumulated Thermal Gain %	Corresponding Increment in Pressure Lbs./sq. in. g	Change in Pressure Lbs./sq. in. g	Approximately Corresponding Pressure Lbs./sq. in. g
3	65	200— 265	250
6	95	265— 360	350
9	140	360— 500	500
12	255	500— 755	750
15	570	755—1,325	1,300

The last column in the above table gives the series of pressures at the turbine stop valve which give, approximately, equal increments of thermal efficiency, if the total steam temperature and vacuum are maintained constant. The appropriate pressure depends, not only on the factors already discussed, but also, in part, on plant size. The curves, etc., used in this section are appropriate to plant having maximum continuous capacities of about 20,000 kw., if the speed is 3,000 r.p.m., and 40,000 kw. if the speed is 1,500 r.p.m. For plant of relatively much larger capacities at the respective speeds, the gains with pressure may be slightly increased, say, by 1 per cent. at 2,000 lbs. if the above capacities are doubled. On the other hand, as the capacity of the plant is reduced, the possible gains with increased pressure decrease fairly rapidly.

For instance, to take an extreme case in the present state of the art, it is probable that the thermal efficiency of a 3,000 kw. set, running at 3,000 r.p.m., with an initial pressure of 250 lbs./sq. in., would be as good as that of a commercial unit of the same capacity, operating with an initial pressure of 750 lbs./sq. in.

It is desirable that some such pressure steps as given in the last column be standardised, and that the pressure appropriate to particular ratings be understood.

At the present time, in the general case, an initial pressure of 250 lbs./sq. in. at the turbine stop valve will give excellent results for maximum continuous ratings of sets below 5,000 kw. at 3,000 r.p.m.; at the same speed, 350 lbs./sq. in. gives excellent results for maximum continuous rating of 10,000 kw., while 600 lbs./per sq. in. will require a 20,000 kw. rating, at 3,000 r.p.m., if the full thermal benefits are to be realised. If the speed necessarily adopted is 1,500 r.p.m., the above ratings should be, approximately, doubled. Of course, as progress is made, the ratings appropriate to any given pressure will tend to decrease.

Effect of regenerative feed heating.

The thermal gains which result from the use of regenerative feed heating depend principally upon the steam pressure adopted, the number of feed heaters used, and whether the boilers are fitted with economisers or air preheaters, or both. The way in which some of these factors affect the result is illustrated by the group of curves shown in Fig. 6, which relate to the conditions holding with a pressure at the turbine stop valve of 600 lbs./sq. in., a total temperature of 700° F., and with a vacuum of 29ins. at the turbine exhaust.

The group of dotted curves shows the thermal gains which are to be expected from the inclusion of from one to seven feed heaters, if an air heater is provided of such capacity that the temperature of the flue gases leaving it is kept down to that which would be obtained with the economiser alone, and without any feed heating. In other words, the air heater is to be of such capacity that the boiler efficiency

is maintained constant as the feed temperature is increased. The full line group of curves, gives the corresponding thermal gain in a boiler—economiser—feed heater installation, in which no air heater is provided, and in which, therefore, the chimney temperature and, therefore, chimney loss increases as the temperature of the feed, leaving the regenerative feed heater increases.

It will be noted that both series of curves betray a well defined maximum gain. The temperature to which feed water should be heated in the regenerative feed heater, will, in good practice, be some 30 to 50° F. less than corresponds to this maximum gain. The decrease, in possible thermal return, which results from this lower feed temperature is insignificant; while the reduction in complication of plant, and the relief in operating difficulty, consequent upon the decrease in air preheater temperature for constant boiler efficiency, amply justify this course.

In Fig. 7, the maximum thermal gains, with regenerative feed heating, have been plotted for various pressures from 200 lbs./sq. in. to 2,000 lbs./sq. in., and for from one to seven feed heaters. The full line curves apply to systems, which incorporate an air heater, while the dotted curves hold if the air heater is omitted.

The following features exhibited by these curves are notable:—

(*a*) The gain resulting from the use of regenerative feed heating, continuously increases but, at a decreasing rate as the pressure is increased, being nearly twice as great at 2,000 lbs./sq. in., as at 200 lbs./sq. in.

(*b*) The addition of an air preheater increases the possible gain resulting with regenerative feed heating by, approximately, 50 per cent.

(*c*) The gain resulting from the addition of one feed heater, continuously decreases as the total number of feed heaters is increased. The gain resulting from the addition of a fifth is, approximately, only 25 per cent. of that which follows the introduction of a second.

(*d*) The number of feed heaters, which is thermally justified, increases only very slightly with pressure, so that the number which should be included is, practically, independent of pressure.

It should be mentioned, that the gains due to feed heating are, practically, independent of the steam temperature at the turbine stop valve, but are affected by the vacuum at the exhaust.

The effect of variations in vacuum can be, approximately, assessed, by making use of the fact that the possible gain is, roughly, proportional to the temperature rise from the vacuum temperature to the feed temperature, corresponding to maximum gain.

Effect of resuperheating.

The savings in fuel which can be obtained, as a result of resuperheating, depend, mainly, upon the proportion of the total expansion which precedes the journey of the steam, to and from the resuperheater, the number of times resuperheating is performed, and the temperature at which the steam leaves the resuperheater.

It is not proposed to consider the thermodynamics of more than one stage of resuperheating, because, at the present time, the extra complication and cost in actual installations, which would be involved in employing two or more reheating stages, as at present conceived, appears to put it outside the bounds of good practice.

The upper part of Fig. 8, shows the percentage of the adiabatic expansion for various pressures, which should precede resuperheating if the steam is to be brought back in the resuperheater to the initial temperature, before the turbine stop valve.

Experience is not yet sufficiently extended, to allow the gain, which can be expected from resuperheating, to be assessed with the same closeness as obtains in the estimates already dealt with in this chapter.

Two possible bases of assessment present themselves, and are shown in Fig. 8, in full and dotted lines. These, probably, represent the upper and lower limits of possible gain. So far as results have been obtained, up to the present, the actual return from resuperheating appears to correspond, approximately, to the mean of these two limits. As experience in reheating extends, it is probable that the upper limit will more and more closely be approached.

The points of interest to be deduced from Fig. 8 are :—

(*a*) That the proportion of the complete expansion, which should precede resuperheating decreases rapidly as the initial pressure increases, being, approximately, 43 per cent. of the adiabatic expansion at 200 lbs./sq. in., and 27 per cent. at 2,000 lbs. per sq. in.

(*b*) That the mean of the two possible limits in gain, due to reheating, is sensibly constant with pressure.

(*c*) That the upper limit of gain in reheating, does not change rapidly with pressure, in fact, the possible gain is increased by, approximately, $\frac{1}{8}$ per cent. for each 100 lbs./sq. in. increase in pressure, at the turbine stop valve.

Quite apart from the thermal possibilities of resuperheating, it has what may, ultimately, prove to be an even more important advantage, in that the resuperheating can be made to reduce the wetness of the steam, in the low pressure end of the turbine to desirable limits; for as the initial pressure is raised

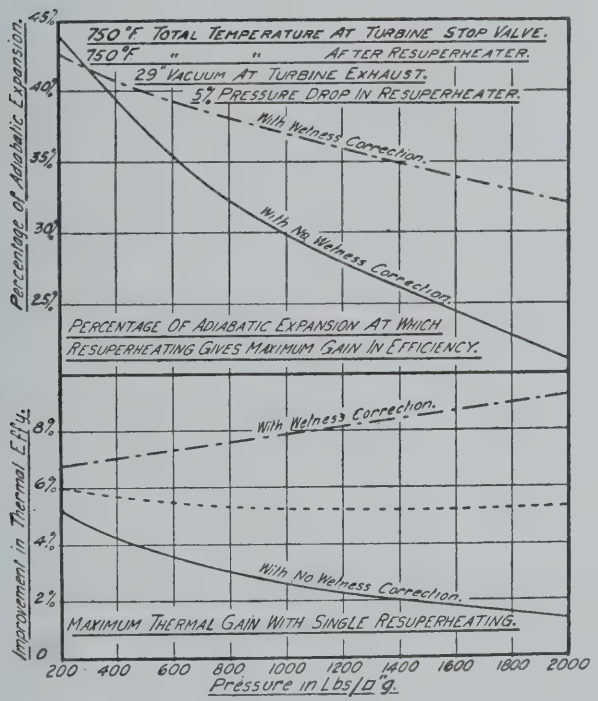

750° F. Total Temperature at Turbine Stop Valve.
750° F. " " After Resuperheater.
29" Vacuum at Turbine Exhaust.
5% Pressure Drop in Resuperheater.
With Wetness Correction.
With No Wetness Correction.
Percentage of Adiabatic Expansion.
Percentage of Adiabatic Expansion at which Resuperheating Gives Maximum Gain in Efficiency.
With Wetness Correction.
With No Wetness Correction.
Improvement in Thermal Efficiency.
Maximum Thermal Gain with Single Resuperheating.
Pressure in Lbs/□"g.

Fig. 8.—*Maximum Gains from Resuperheating.*

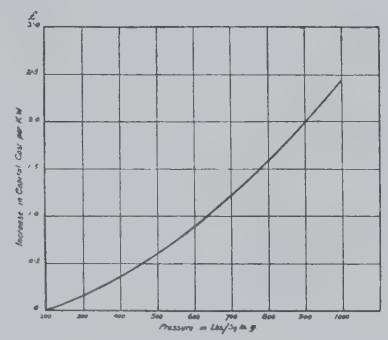


Fig. 9.—*Increase of Capital Cost with Pressure.*

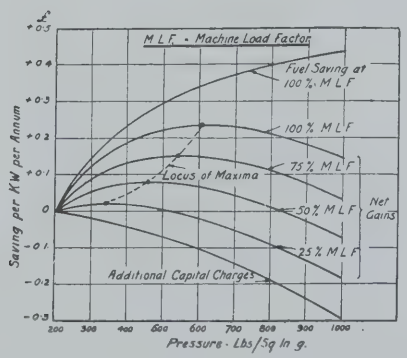


Fig. 10.—*Variation in Savings with Pressure.*

with constant initial steam temperature, the amount of steam condensed, as the result of the work performed in the turbine, increases rapidly. Thus, with 200 lbs./sq. in. initial pressure, and 700° F. initial temperature, the fraction of the original steam, which is water, on leaving the last row of blading is about 9.5 per cent.; with 600 lbs./sq. in., this rises to 15.25 per cent., and with 1,200 lbs./sq. in. it reaches 20.3 per cent. Such a high percentage of water, as would result from the higher pressures, may be difficult to work with. It follows that recourse to resuperheating may prove imperative, if pressures, much above 500 lbs./sq. in., are to be used, unless it also proves possible to work satisfactorily with initial temperatures, above 800° F.

Up to the present, we have been considering the thermal gains offered by increasing steam pressures, on the whole of the generating plant.

A further possibility deserves consideration. Part of the boiler and turbine plant may be laid out for operation at some moderate pressure, say 350 lbs./sq. in., while a proportion of the boiler plant may be installed, to generate steam at some considerable pressure, say, above 1,000 lbs./sq. in., which steam

will be passed through back pressure turbines, and exhausted from there into the medium pressure main at 350 lbs./sq. in.

In such cases, the steam from the back pressure turbine may, and preferably should, be passed through a resuperheater to bring its temperature back to the initial temperature of the steam leaving the 350 lbs./sq. in. boilers. It is possible, that this system may have special attractions where it is desired to modernise a station having good steam plant, operating with low or moderate pressures, but, otherwise, efficient and in good order.

Economic aspects in choice of steam pressure.

It has already been pointed out that, the choice of initial steam temperature will be determined, almost entirely, by metallurgical and design conditions. The increased cost of utilising such increased temperature, as will satisfy these other conditions, will always be outweighed by the savings in fuel, which will flow directly from such use.

It was, also, pointed out that the vacuum adopted will be determined, almost entirely, by site considerations. The economic considerations which should decide the question are fairly generally understood, and the margin of variation left to experienced engineering judgment is very limited. However, the general method of arriving at an economically balanced judgment in the choice of vacua, is, practically, the same in type as will be illustrated in arriving at the economic pressure.

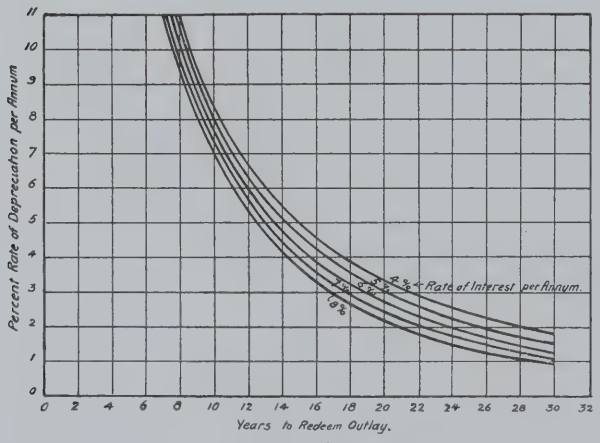


Fig. 11.—*Rates of Depreciation.*

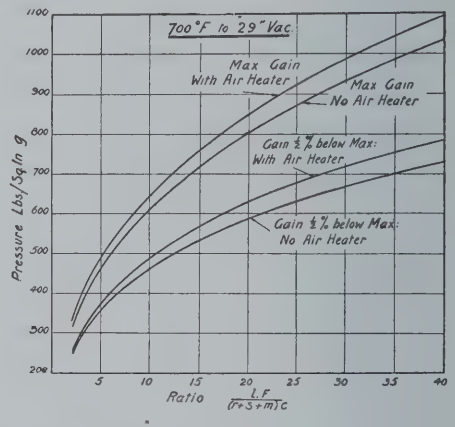

700°F to 29" Vac.
Max Gain With Air Heater
Max Gain No Air Heater
Gain ½% below Max: With Air Heater
Gain ½% below Max: No Air Heater
Pressure Lbs/Sq In g
Ratio

Fig. 12.—*Economic Pressures for varying conditions.*

With regard to the choice of a suitable pressure, at the present time, economic considerations predominate over both metallurgical and design conditions. In order to determine the advantage offered by increased steam pressure, in any particular case, it is necessary to balance the value of the annual fuel saving which would result from its adoption, against the increased capital charge involved, as a direct result of the increased expenditure incurred. The economic pressure is, obviously, the one at which the difference between the increase in annual saving, and the increase in capital charges is a maximum. In order to focus the solution of the problem, we will investigate a particular case, and then show exactly how a new solution is to be obtained, for any variation from this case.

A plant including four feed heaters and economiser, has been chosen for detailed comparison; calculations have been made for varying pressures, and with and without air heater, the feed heating being carried to the optimum temperature in each case. The boiler efficiency has been taken as 84 per cent., and the generator efficiency as 96 per cent. In the first place, coal has been taken as costing 15s. per ton, with a calorific value of 11,500 B.Th.U. per lb., and the increase in capital cost of plant, per kilowatt (over the cost at the basic pressure of 200 lbs./sq. in.) has been taken as shown in the graph of Fig. 9. This capital cost curve includes allowance for boilers, turbines and all auxiliaries mentioned, and for the buildings containing them. It will later be shown, how results may be rendered valid with altered costs of plant and of coal.

Fig. 10 shows the alteration in cost per kilowatt per annum, with varying initial pressure, for a special case of a plant including air heater. The uppermost curve indicates the saving in cost of fuel per kilowatt-year; the lowest curve, the additional annual capital charges to cover interest, depreciation and maintenance, as explained below, at a total rate of 12 per cent. The two curves can, obviously, be set against one another as they stand, only when the plant is working continuously at its full rated capacity, that is, when the machine load factor is 100 per cent. It must be pointed out that the machine load factor to be taken is the average actual output for the whole period of redemption, covered by the rate of depreciation, divided by the maximum continuous rating of the set.

The curves marked "100 per cent. M.L.F.," "75 per cent. M.L.F.," etc., show the net savings with various machine load factors: they are derived by multiplying the basic fuel savings by the respective load factors and subtracting the additional capital charges. The pressure for maximum gain is seen to vary with the load factor, from 606 lbs./sq. in. at 100 per cent. M.L.F. to 340 lbs. per sq. in. at 25 per cent. M.L.F., with the particular conditions assumed.

The following table of pressures for maximum gain with varying load factors and rates of capital charges, has been obtained from such graphs. The figures apply only to the particular prices assumed for plant and fuel.

PRESSURE FOR MAXIMUM GAIN (lbs./sq. in. g).

Expansion from 700° F. to 29ins. Vacuum with Four Feed Heaters and Economiser, and with and without Air Heater, at varying Load Factors and rates of Capital Charges.

	Rate of Capital Charges	Load Factor.			
		100%	60%	50%	30%
With Air Heater	12%	606	495	459	367
Without Air Heater	12%	575	466	433	350
With Air Heater	18%	516	417	385	306
Without Air Heater	18%	477	396	366	293

Many engineers, who do not regard the use of high pressures as an end in itself, are not accustomed to press such conditions to the point of maximum return, but are satisfied to carry such change to the point only where further increases cease to bring sensibly increased returns. Such engineers might, for instance, choose their pressure at the point where the gain is $\frac{1}{2}$ per cent. less than the maximum, and such a course will be found to result in the selection of an appreciably lower pressure than corresponds to the maximum gain.

A corresponding table of pressures for gain $\frac{1}{2}$ per cent. less than the maximum is as follows:—

PRESSURE FOR GAIN $\frac{1}{2}$ PER CENT. LESS THAN MAXIMUM (lbs./sq. in. g).

Expansion from 700° F. to 29ins. Vacuum with Four Feed Heaters and Economiser, with and without Air Heater, at varying Load Factors and rates of Capital Charges.

	Rate of Capital Charges.	Load Factor.			
		100%	60%	50%	30%
With Air Heater	12%	460	379	355	285
Without Air Heater	12%	439	363	345	275
With Air Heater	18%	394	325	300	238
Without Air Heater	18%	378	312	289	227

It is evident that the total cost of fuel would be unchanged, if the price of fuel were, for instance, doubled and the load factor halved, and that the fixed capital charges would be the same, if the rate of total capital charges were, say, doubled, but plant could be purchased at half the price increases assumed; so that one curve of savings can be made to apply to a series of different conditions. An algebraic investigation of the effect on economic pressure of simultaneously varying conditions follows:—

Let r = rate of interest (% per annum) on the additional capital involved.

s = allowance (% per annum) on additional capital for sinking fund (sometimes called depreciation or redemption allowance).

m = average additional maintenance charges (% per annum) over the full redemption period.

l = average machine load factor (%) as already defined.

C = *additional cost of plant* (*under any assigned circumstances*) additional cost of plant already assumed.

F = *cost of fuel referred to calorific value* (*under any assigned circumstances*) cost of fuel already assumed.

If fuel costs p shillings per ton and has a calorific value of t B.Th.U. per lb., then evidently

$$F = \frac{p}{t} \times \frac{11{,}500}{15}$$

The period of redemption, n years, is given by the relationship,—

$$n = \frac{\log\left(l + \frac{r}{s}\right)}{\log\left(l + r\right)} \; ;$$

corresponding values of r, s and n may easily be found from Fig. 11, which is plotted from the relationship just mentioned.

If, for any given pressure p, our assumed capital cost is Pc, and our calculated fuel saving per annum is P_F (Pc and P_F are both functions of p), then, under other assigned conditions, the capital cost will be C.Pc, and the fuel cost will be F.P_F. Then for the actual station, per kilowatt of *installed capacity* per annum: the fuel cost is l. F.P_F.,
and the additional charges are (r + s + m) C.Pc.,
hence the nett saving is l. F.P_F. — (r + s + m) C.Pc.
Therefore,

$$\frac{\text{nett saving}}{\text{total fuel cost}} = 1 - \frac{(r + s + m)}{l.\ F.}\ C.\ \frac{Pc}{P_F.}$$

$\frac{Pc}{P_F}$ depends on p. only: and, hence, when $\frac{(r + s + m).\ C}{l.\ F}$ is assigned, there is a certain value of p. which makes the nett saving a maximum. In other words, the value of p. for maximum net gain may be plotted as a function of $\frac{l.\ F}{(r + s + m)\ C}$

The same is true when p. is to correspond to any gain less than the maximum by a given amount. Fig. 12 has, accordingly, been plotted to give the pressure for maximum gain, or for gain $\frac{1}{2}$ per cent. less than the maximum in terms of—

$$\frac{l.\ F}{(r + s + m)\ C.}$$

Fig. 12 may thus be applied to determine the economic pressure in any particular case. For instance, given a plant with capital costs as assumed, fuel costs double those assumed, and r = 5 per cent., s = 7 per cent., m = 3 per cent., l = 30 per cent. we have

$$\frac{l.\ F}{(r + s + m)\ C} = \frac{30 \times 2}{(5 + 7 + 3) \times 1} = 4$$

and we find the pressure for maximum gain to be 450 lbs./sq. in., or 425 lbs./sq. in., according as the plant has, or has not, an air heater.

As a further illustration of the use of this method, the following table of economic pressures is added, for either fuel cost of 30s. per 11,500 B.Th.U. lb. (*i.e.*, twice that previously assumed), or else, for increases in purchase price of plant with pressure one half those given in Fig. 9.

The pressures corresponding to $\frac{1}{2}$ per cent. less than the maximum gain are also given. These should be compared with the tables previously presented.

ECONOMIC PRESSURES WITH HALVED CAPITAL COSTS.

Rate of increase of capital cost half that assumed in paper. Fuel cost unchanged. Expansion from 700° F. to 29ins. Vacuum with Four Feed Heaters and Economiser, and with and without Air Heater at varying Load Factors and Rates of Capital Charges.

PRESSURE FOR MAXIMUM GAIN (lbs./sq. in. g).

	Rate of Capital Charges.	Load Factor.				
		100%	60%	50%	30%	20%
With Air Heater ..	12%	794	652	606	495	417
Without Air Heater ..	12%	748	616	575	466	396
With Air Heater ..	18%	680	555	516	417	349
Without Air Heater ..	18%	641	526	487	396	333

PRESSURE FOR GAIN $\frac{1}{2}$ PER CENT. LESS THAN MAXIMUM (lbs./sq. in. g).

	Rate of Capital Charges.	Load Factor.				
		100%	60%	50%	30%	20%
With Air Heater ..	12%	581	491	460	379	326
Without Air Heater ..	12%	554	465	439	363	312
With Air Heater ..	18%	521	421	394	325	271
Without Air Heater ..	18%	483	406	378	312	261

Chapter 4.

THE RATIONAL UTILISATION OF STEAM IN ENGINES AND TURBINES.

By W. J. Kearton, M.Eng., A.M.I.Mech.E., A.M.Inst.N.A.

In traversing this aspect of steam utilisation, the present position of the steam prime mover is reviewed and indications given briefly of the theoretical and practical considerations which lead to an amelioration of the thermal efficiency.

Factors which affect the thermal efficiency fall into two distinct categories. Firstly, there are those which depend on the physical properties of the working substance—water, and on the nature of the cycle of thermal operations through which that substance passes. These factors are known fairly accurately, and the results of any variation in the cycle can be more or less confidently predicted. In the second category, we have the unavoidable modifications to the ideal cycle due to the practical method of carrying it out. These modifications, owing to the present imperfect state of our knowledge can only be judged by actual tests or rough calculations of a semi-empirical nature. The factors falling into the second category are, of course, of the utmost importance and may be said to guide engineering practice very largely. The designer of steam plant, whether it be boilers, engines, turbines, or condensing plant can modify the influence of these particular factors to a greater or lesser extent in the process of design.

A third and none the less important influence is that of economy of money and material. This is closely related to the design factor, and as fuel costs may only amount to about 40 per cent. of the total generating costs, the cost factor must always be borne in mind.

INFLUENCE OF THE PHYSICAL PROPERTIES OF WATER AND STEAM AND OF VARIATIONS OF THE THERMAL CYCLE ON THERMAL EFFICIENCY.

Influence of Vacuum. It is well known that the thermal efficiency of a perfect heat engine can never exceed $\frac{T_1 - T_2}{T_1}$ where T_1 is the upper limit of temperature of the steam on the absolute scale and T_2 is the lower limit of temperature on the same scale. Whatever limit practical considerations may set to the value of T_1, it is apparent that T_2 must be made as low as possible.

The actual value is conditioned by the fact that heat must be rejected by the steam to the cooling water supplied to the condenser, that some rise of temperature must be permitted to the cooling water and further, that some temperature difference must exist between the steam and cooling water in order to effect the required transmission of heat in a condenser of reasonable proportions.

The most important factor is the temperature of the available circulating water. River or canal water will have an average temperature in the region 45° F. to 55° F. If the water must be cooled in towers, then the temperature of the water returning from the towers will normally be from 75° F. to 80° F. If we assume that the weight of cooling water supplied per pound of exhaust steam is 80 lb. and that the difference between the temperature of the exhaust and that of the cooling water leaving the surface condenser is 6° F., then with river water at 50° F., the vacuum would be 29.3 inches (30 inch barometer) and with cooling tower water at 80° F., the vacuum would be 28.2 inches. If we further assume that steam is supplied initially at 300 lb. per sq. inch gauge and superheated 200° F., then in the first case the theoretical thermal efficiency is 35.7 per cent., and in the second case 33.0 per cent. The difference between these two figures is 2.7 per cent. absolute or 8.2 per cent. on the lower figure.

With cooling towers, there is an inevitable loss of circulating water by evaporation. This usually amounts to about 60—70 per cent. of the actual weight of main condensate, and if water is relatively scarce its loss becomes a serious item. Its importance can perhaps best be gauged by considering an example. In a station with an average load of 50,000 kw. the loss of water, per day, will be from 3,200 to 3,800 tons.

It will be apparent, therefore, that a plentiful supply of cold circulating water is a very essential and desirable feature of any site for a power station equipped with steam turbines. The question must,

in every case, be regarded from the financial, as well as the thermal side, for the cost of river work may be excessive.

Whilst every care should be taken to realise the highest vacuum permissible in steam turbine plants, the same remark does not apply to reciprocating steam engines. In the turbine, expansion is always complete. In the reciprocator, however, the volume of the low-pressure cylinder is really very limited, and release of pressure usually occurs at an appreciable pressure—say, about 12 lb. per sq. inch absolute, or even more. As this is an important reason for the superiority of the turbine — at least in units of moderately large size—a little further amplification will be given.

The theoretical cycles of operation for the turbine and reciprocator are shown in the T—ϕ chart, Fig. 1. The conditions assumed are as follows :—

Initial steam pressure	...	200lb./sq. in. abs.
Initial condition	...	Dry and saturated.
Release pressure in reciprocator	...	12lb./sq. in. abs.
Common exhaust pressure	...	28″ vacuum.

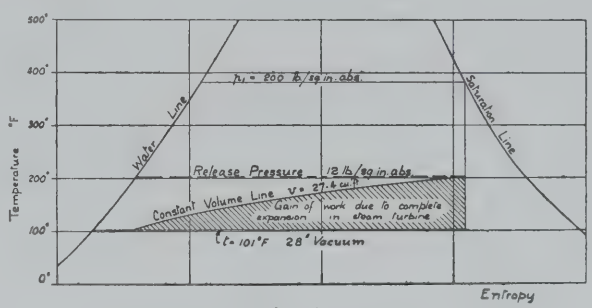


FIG. 1.

The loss due to constant volume release in the reciprocator is shown by the cross-hatched area. The theoretical work done and the thermal efficiency in the two cases for varying vacua are shown graphically in Fig. 2. The curves speak for themselves.

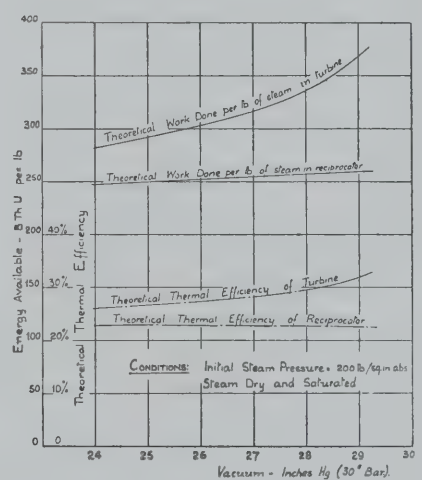


FIG. 2.

Influence of Pressure. As shown above, the lower limit of temperature in the system will be settled by the temperature of the cooling water available, the upper limit by the mechanical properties of the materials available for boiler, superheater, piping and turbine construction. The present operating limit, allowing for the inevitable fluctuations in working, is about 800° F. In a recent paper, Professors Mellanby and Kerr foreshadowed an upper limit of 900° F. for high-pressure turbine plants.

It is possible to adopt a high limit of temperature in two ways, viz.: (1) with a moderate pressure and a high degree of superheat, (2) with a very high pressure and moderate superheat. Owing to the small thermal capacity of superheated steam, the theoretical gain in thermal efficiency by the adoption of a high superheat is small. There is, however, one great advantage. The point in the expansion at which the steam loses its superheat occurs at a lower pressure the higher the initial superheat. This has a definite beneficial effect, both in engines and turbines. In steam engines, the loss due to condensation occurring on the cylinder walls, with the consequent re-evaporation, is appreciably diminished. The precise cause of the benefit observed in turbines, due to lingering superheat, is in some doubt. It may be due to reduced blade friction losses, it may be traced to diminished supersaturation losses, or it may possibly be due to both causes. As the theoretical and economic aspects of high pressures and temperatures are being dealt with in another chapter, no further mention need be made of the subject. Some practical aspects will be mentioned later.

The Regenerative Steam Cycle. It is common practice to preheat the feed water prior to its entry into the boiler. This is usually done in the so-called " economiser," which is virtually an extension of the boiler-heating surface provided to reduce the temperature of the escaping flue gases. The dew point

of the products of combustion is, normally, about 100° F. with coal fuel, and about 110° F. to 115° F. with oil fuel. As the hotwell temperature is frequently as low as 65° F. to 70° F., some preheating is essential before the water can be pumped into the economiser, otherwise sweating would occur on the outside of the economiser tubes and corrosion would take place.

Such preheating can be effected efficiently by low-grade heat such as from exhaust steam from auxiliaries, etc. In the majority of power stations, the auxiliaries are now electrically driven and the necessary supply of exhaust steam is not forthcoming, except from (1) steam jet air pumps, and (2) house turbine exhaust, when a house turbine is installed.

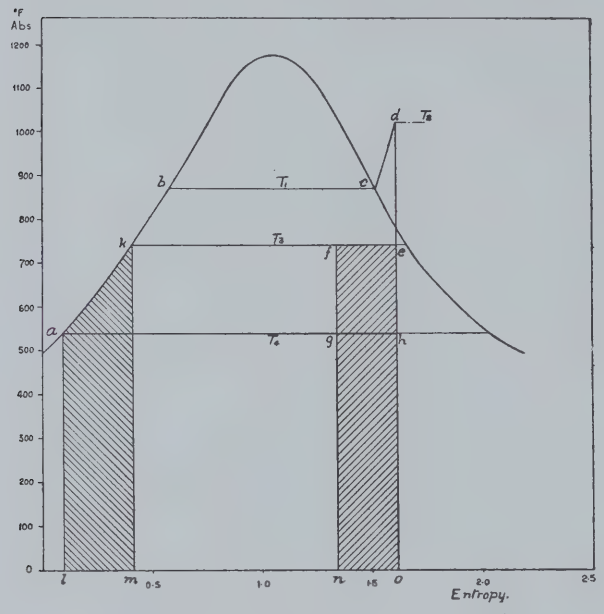


FIG. 3.—*T—ϕ Chart for Regenerative Steam Cycle.*

By withdrawing steam from the main turbine at one or more stages, where the temperature of the expanding steam is suitable for feed heating, it is possible to preheat the feed so that the thermal efficiency of the turbine portion of the plant is increased. The heater is of the surface type and may be integral with the turbine casing, or quite independent of it. Steam condenses in the heater giving up latent heat. The condensate is drained off and mixed with the feed water at the suction side of the extraction pump. The process for single stage heating and frictionless adiabatic expansion is illustrated by the T—ϕ chart, Fig. 3. It is assumed that the feed water is heated from T_4 to T_3 by steam tapped off from the turbine at T_3. The heat supplied per pound of feed is represented by the area l a k m, and since the heat rejected, per lb. of steam condensed in the heater, is equal to the area m k e o, the fraction of the turbine steam condensed in the feed heater is equal to $\frac{\text{Area l a k m}}{\text{Area m k e o}}$.

Thus, if we show on the T—ϕ chart mass-entropy, the condensation process is represented by e f and the area, n f e o, is equal to l a k m.

It is clear that the work done, per lb. of steam is less than that done in the simple cycle, but the heat rejected is also less. The resultant thermal efficiency is thus increased.

A further illustration is given in Fig. 4, in which are shown heat quantities relating to the following conditions :—

Initial steam pressure	250lb. per sq. in. abs.
Initial superheat ...	150° F.
Final pressure ...	0.5 lb. per sq. in. abs.
Pressure at which steam is bled for heating feed water	30lb. per sq. in. abs.

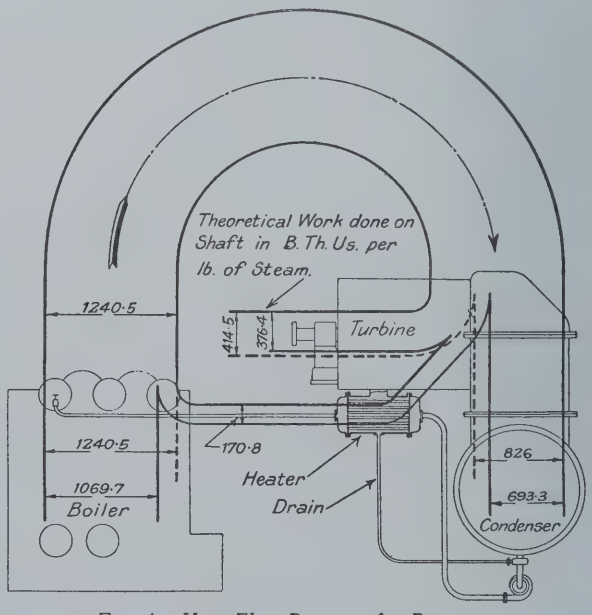


FIG. 4.—*Heat Flow Diagram for Regenerative Feed-heating System.*

The figures given in Fig. 4 were derived on the assumption of adiabatic and frictionless expansion. The relevant data are tabulated in Table I.

TABLE I.—COMPARISON OF RANKINE AND REGENERATIVE CYCLES.

	Rankine Cycle.	Regenerative Cycle.
Heat supplied to water and steam externally	1240.5	1069.7
Work done	414.5	376.4
Thermal efficiency, per cent.	33.4	35.2

The gain is thus 1.8 per cent. absolute, or 5.4 per cent. on the original figure. A slightly higher gain may be realised in practice where the condition of the extracted steam is affected by turbine losses.

When it is required to heat feed water through any given range of temperature, the process may be effected with somewhat greater efficiency when a number of heaters is arranged in series, and the heaters are coupled to turbine stages, in which the steam temperature is continually ascending. The feed water is thus heated in a number of steps or stages and such process is known as "multi-stage" feed heating.

The approximate gains in thermal efficiency for the turbine alone for single stage and multi-stage feed heating are shown in Fig. 5, from which it is clear that quite appreciable gains are possible with extensive feed heating in this manner.

The difficulty of designing the exhaust end of large powered steam turbines, with a low terminal pressure, is eased to some extent when regenerative feed heating is adopted. In the 50,000 kw. set at the Crawford Avenue Station, Chicago, the weight of steam extracted for feed-heating purposes is no less than 22 per cent. of the steam entering the turbine. The cost of providing heating surface is thus partly compensated by the reduced cooling surface in the condensers, and may be more than balanced by the reduced cost or entire elimination of the usual economisers.

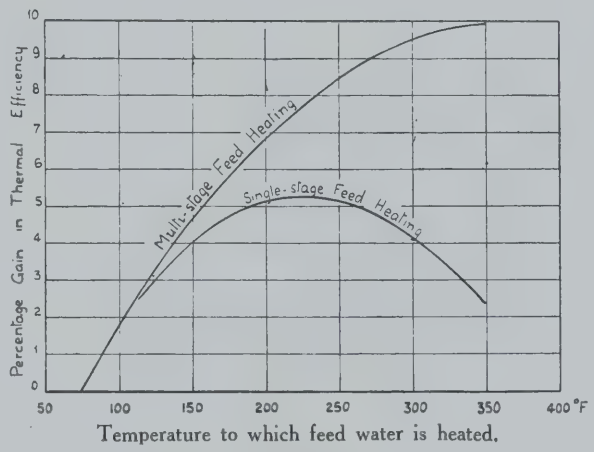


FIG. 5.—*Gain in Thermal Efficiency due to Regenerative Feed Heating.*

Air Heating. The partial, or entire, elimination of the water economiser, consequent upon the adoption of "bleeding," naturally involves a higher flue-gas temperature at the base of the stack, and, as a result, the efficiency of the boiler plant is somewhat reduced. The precise influence depends on the conditions, but the resultant gains with single or multiple-stage heating are considerably less than those shown in Fig. 5 unless steps are taken to reduce the chimney loss. Once again, the principle of regeneration is a solution of the problem, and a large proportion of the heat remaining in the flue gases may be utilised for preheating the combustion air. Air heaters are not new. They have been used very successfully for years in marine work, where considerations of weight and space occupied make them a very desirable form of "economiser." Since the introduction of bleeding in land stations, however, their use has been extended more and more.

From almost every point of view, air heating is an attractive proposition. By providing a large surface, the flue gases may be cooled to a fairly low temperature. The heating surface is provided cheaply, as none of the parts are under pressure and small leakages are immaterial. The use of hot air promotes better combustion. A higher furnace temperature is obtained and more heat is transmitted by direct radiation.

In boilers of the ordinary type, with chain grate stokers, trouble may be encountered in two directions when the combustion air is preheated. The stoker links oxidise badly and the brickwork in the furnace is apt to soften or run. As trouble is frequently experienced with brickwork with a supply of combustion air at normal temperatures, it is not surprising that difficulties arise when hot air is supplied to the furnace.

The solution to this problem is now being sought in two directions: (1) by the use of protected walls and furnace heating surface in pulverised fuel plants. (2) by the use of water-cooled grate bars and protected water-cooled walls and furnace heating surfaces in stoker-fired units.

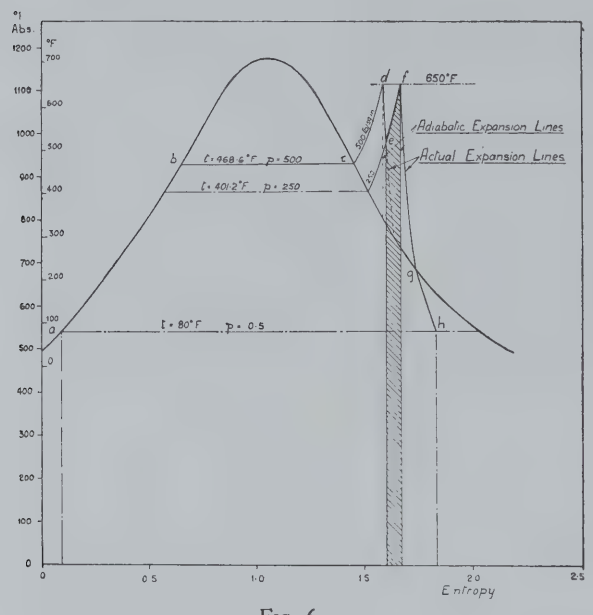


FIG. 6.

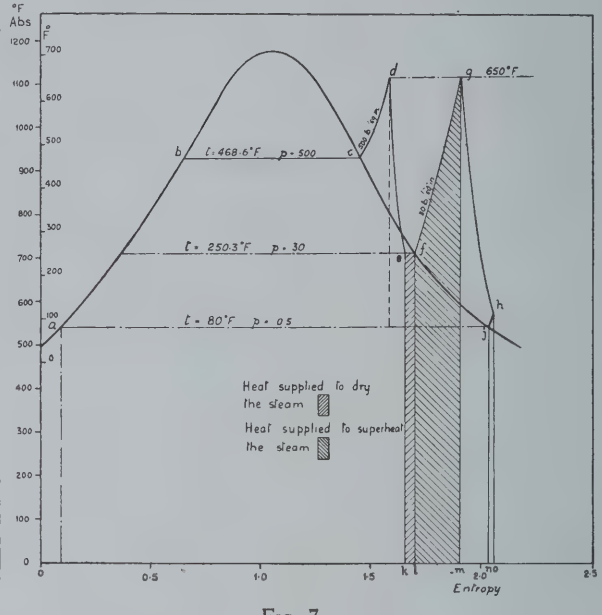


FIG. 7.

T — ϕ *Charts for Reheating Cycle.*

The Reheating Cycle. Steam supplied to the turbine in a superheated state will, sooner or later, in the expansion through the turbine cease to be superheated. Whether it immediately becomes wet, or whether it remains dry and becomes super-saturated is not definitely known. There is some evidence that the steam probably continues to expand for some time in the supersaturated and, therefore, supercooled state.

The particular point in the expansion at which the steam ceases to be superheated, depends on the initial degree of superheat and also on the turbine efficiency. The higher the initial superheat and the less efficient the turbine, the lower the pressure at which the change of state occurs, whereas with a moderate degree of superheat and a high efficiency ratio the steam will cease to be superheated much earlier in the expansion.

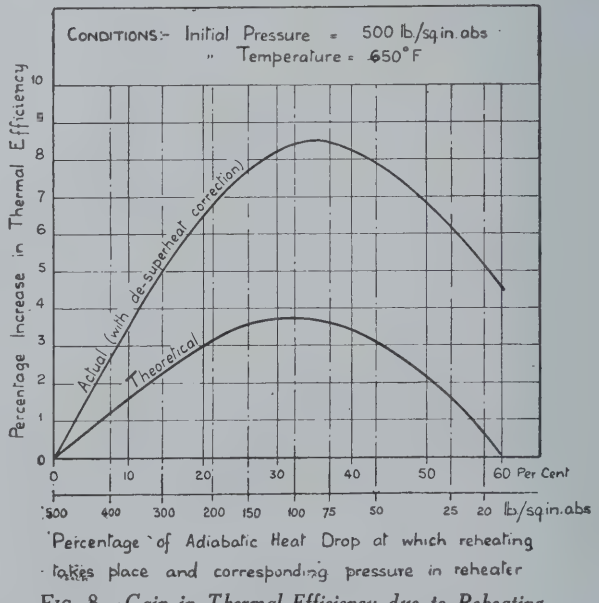

CONDITIONS:- Initial Pressure = 500 lb/sq in abs
" Temperature = 650°F
Percentage Increase in Thermal Efficiency
Actual (with de-superheat correction)
Theoretical
Per Cent
lb/sq in abs
Percentage of Adiabatic Heat Drop at which reheating takes place and corresponding pressure in reheater

FIG. 8.—*Gain in Thermal Efficiency due to Reheating.*

When reheating is done once in the cycle (and it is rarely, if ever, done more than once) there is, in every case, a most efficient reheating pressure. This point will be illustrated by means of Figs. 6 and 7. In each case, the initial steam pressure is 500 lbs., per sq. inch, abs., and the initial steam temperature 650° F. The exhaust pressure is 0.5 lbs. per sq. inch abs. In case I., illustrated by Fig. 6, the steam is extracted for reheating at a pressure of 250 lbs. per sq. inch abs., after only about 15 per cent. of the total work has been done. When allowance is made for losses, it is found that the steam is still super-

heated at e by about 110° F. The additional heat supplied in the reheater to raise the steam temperature to its former value is shown by the cross-hatched area. The further expansion of the steam is represented by the curved line f g h, the final dryness fraction of the exhaust steam being about 0.90. The steam becomes just dry at g, at 20 lbs. per sq. inch abs. In the second case, the steam is assumed to be sent to the reheater, after expansion to 30 lbs. per sq. inch abs., about half the total work having been done. It will be seen that the steam has already lost its superheat and a relatively large amount of heat, represented by the area k e f g m, must be supplied by the reheater. On the other hand, the exhaust steam from the turbine is still superheated by some 30° F., and a comparatively large amount of heat is rejected in the condenser.

The two cases considered above may be regarded as rather extreme cases. In the first, the process of reheating is carried out too early in the expansion; in the second, it is too late. The best results are

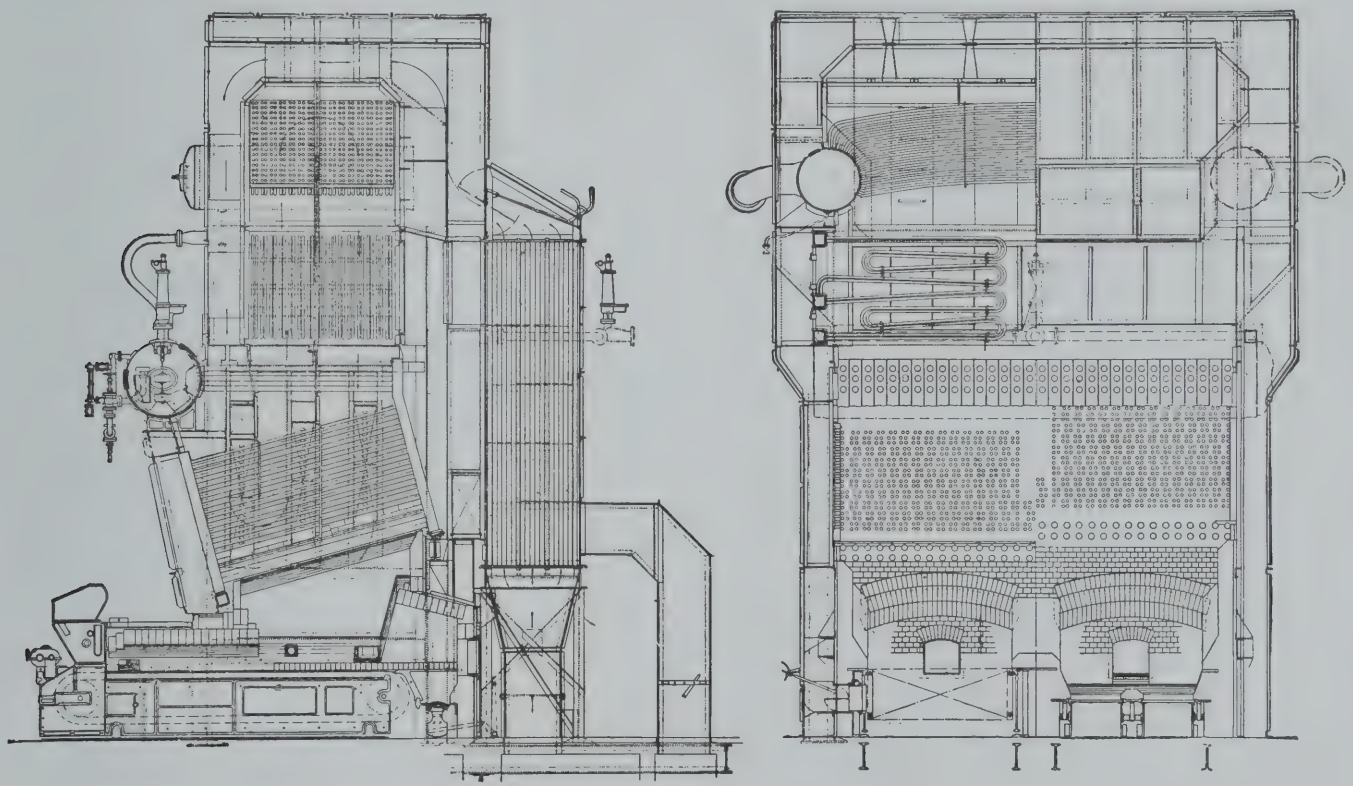


FIG. 9.

obtained when the steam is withdrawn after from 32 to 40 per cent.* of the work has been done, the optimum percentage depending on the initial steam pressure. In order to keep down the size of the steam pipes connecting the turbine and reheater, it is usual to reheat the steam at a pressure somewhat higher than that which would appear to give the maximum thermal gain. Reheating is doubtless a costly elaboration, and the percentage gain, on a purely theoretical basis, is disappointingly small, particularly with high-pressure steam. It appears, however, that owing to the reduction of losses caused either by super-cooling, or wetness, the actual gain in thermal efficiency is considerably greater than that predicted by theory. The influence of this factor may be gauged by the curves given in Fig. 8†

Reheating in Practice. Reheating may be effected in the following ways:—(*a*) By means of reheaters in parallel arranged in each boiler unit, or a number of the units. The latter is the arrangement adopted

* See Paper "Economic Value of Increased Steam Pressure," by H. L. Guy, Proc.I.Mech.E., No. I., 1927, page 119.
† Reproduced from "Some Recent Developments in Large Steam Turbine Practice," by K. Baumann, Proc. I.E.E., 1922.

at the North Tees Power Station. There are two turbines of 20,000 kw. maximum continuous rating each. The leading particulars of the boilers are as follow :—

	With Reheater.	Without Reheater.
Number installed	5	5
Boiler heating surface, sq. ft.	6,756	6,980
Heating surface of Superheater, sq. ft.	3,050	3,050
Heating surface of Reheater, sq. ft.	5,490	—
Heating surface of Air Heater, sq. ft.	10,560	9,245
Grate area, sq. ft.	196	168

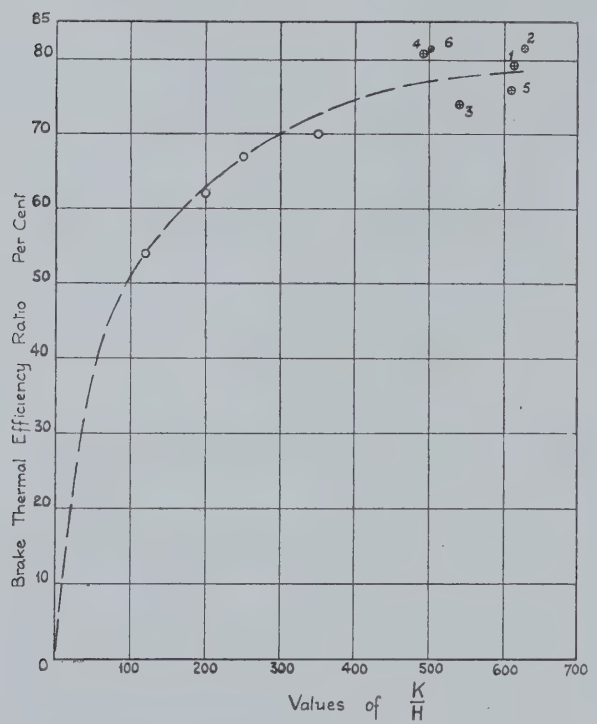


Fig. 10.

References (1) 30,000 *kw. Impulse Turbine.*
(2) 11,000 *kw. Impulse Turbine.*
(3) 10,000 *kw. Impulse Turbine.*
(4) 25,000 *kw. Reaction Turbine.*
(5) 15,000 *kw. Reaction Turbine.*
(6) 1,000 *kw. Back Pressure Turbine.*

The feed water is heated by bled steam to 300° F., and there are no economisers. A boiler of this type is shown in Fig. 9. The reheater tubes are seen above the superheater. (*b*) By means of an integral superheater or reheater of especially large surface incorporated in one of the boilers supplying steam to the turbine. This is the method employed in the Crawford Avenue Station, Chicago. There are five boilers having the following dimensions :—

	4 Normal Boilers (each)	1 Reheat Boiler
Heating surface of Boiler, sq. ft.	16,615	6,007
Heating surface of Superheater, sq. ft.	2,700	1,700
Heating surface of Reheater, sq. ft.	—	14,000
Heating surface of Economiser, sq. ft.	11,054	11,054
Heating surface of Air Heater, sq. ft.	10,000	10,000

In order to minimise pipe friction and radiation losses, the reheat boiler is arranged as near to the turbine as possible. (*c*) By means of high-pressure, highly superheated steam. This method is not new, but has recently been brought to the front by Mr. F. Samuelson. In a typical case, steam is generated at a pressure of 310 lbs. per sq. inch gauge and superheated to a temperature of 1,000° F. Such steam is then passed through a heat exchanger placed near the turbine. The steam to be reheated enters the heat exchanger at a pressure of 31 lbs. gauge, and a temperature of 320° F. In passing through the heat exchanger, its temperature is raised to about 600° F., while that of the live steam is lowered to about 700° F., which is the supply temperature to the main turbine. A temperature drop from 1,000° F. to 960° F. due to radiation is expected between the boilers and the reheater.

It will be seen that the live steam is made, in the last case, the conveyor of heat from the products of combustion to the steam which is to be reheated. The long pipe connections between the turbines and reheater boiler, and all the disadvantages appertaining to them, are thus eliminated, and it may be shown that, when allowance is made for the elimination of losses caused by de-superheating, the efficiency to be realised by a plant of this kind is practically the same as that obtained by the direct expansion of steam, from the same pressure and 1,000° F. to condenser pressure.

There is one aspect of the reheating problem which must not be overlooked, particularly in plants where the volumetric capacity of the reheaters and the connecting pipes is appreciable. It is apparent that in such cases, there is a considerable mass of steam in the system over which the governor has no

further control, and in the event of a sudden reduction of load, the speed of the turbine and alternator may reach a dangerous limit. There are two methods of overcoming the difficulty, viz.: (1) by causing an overspeed governor to break the vacuum in the condenser, and, (2) by causing an overspeed governor to release the steam in the reheater to the main condenser (through properly designed nozzles) and simultaneously to close a throttle valve in the pipe connecting the reheater to the low-pressure turbine.

SOME PRACTICAL ASPECTS OF STEAM TURBINE DESIGN AFFECTING THE ECONOMY OF FUEL.

High Rotational Speeds. The efficiency with which any type of steam turbine converts the energy available due to the expansion of the steam in the nozzles into work done *on the blades*, depends almost entirely on the ratio of blade velocity to steam velocity. This important ratio is termed the blade speed ratio. It may easily be shown that, for each particular type of turbine, there is some value of the blade

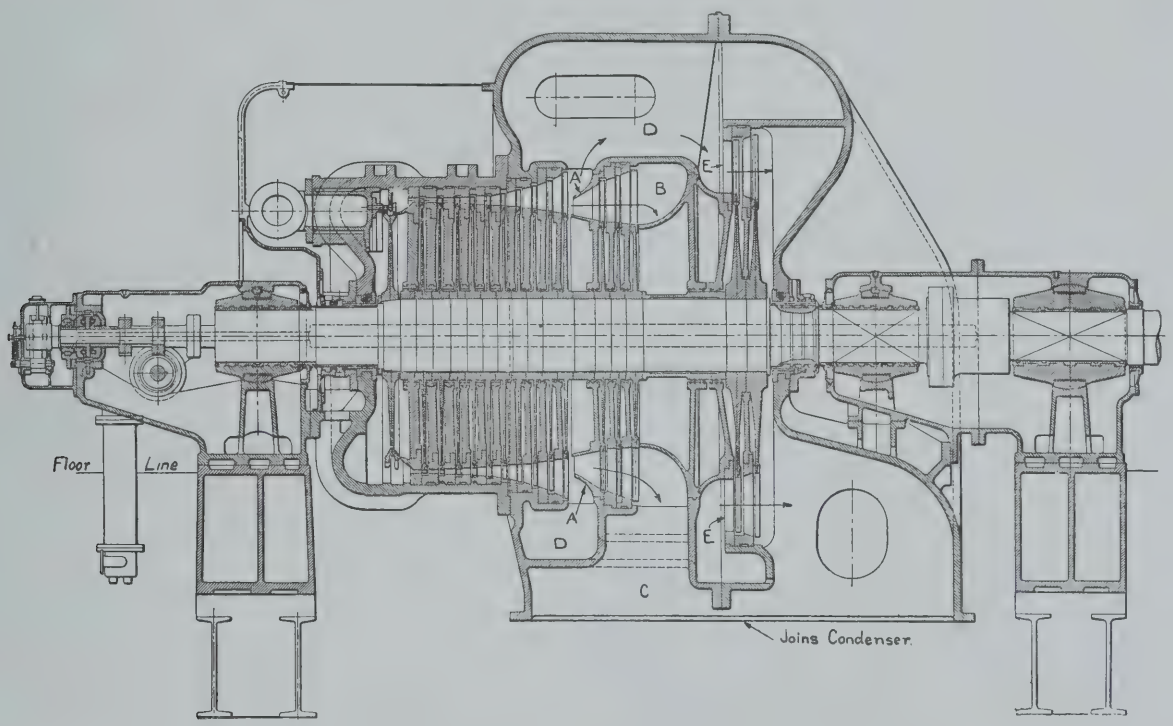


FIG. 11.—18,750 *kw. Impulse Steam Turbine at Dalmarnock Power Station.*

speed ratio for which the hydraulic efficiency is a maximum. This optimum value, which is hardly affected by blade friction losses, is given in the following table:—

TABLE II.

Theoretical Values of the ratio: $\frac{\text{Mean Blade Velocity}}{\text{Steam Velocity}}$ to give maximum blade efficiency.

Type of Turbine.	Nozzle Outlet Angle.			
	20°	30°	40°	50°
Impulse-reaction (Parsons)	0.940	0.866	0.766	0.643
Impulse 1-row wheels	0.470	0.433	0.383	0.322
„ 2-row wheels	0.235	0.216	0.192	0.161
„ 3-row wheels	0.156	0.144	0.127	0.107

As the efficiency is greater when the smaller nozzle angles are used, it is preferable to retain as small a nozzle angle as practicable until, at the low-pressure end of the machine, the large steam way required makes it imperative to adopt large nozzle angles. For these reasons, nozzle angles of 12° and 14° are common at the high-pressure end, and angles of 25° to 35°, and even more, are sometimes used at the exhaust end.

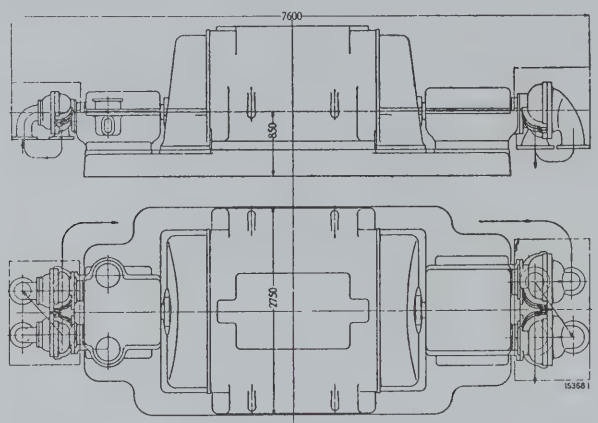


FIG. 12.—*High-pressure 10,000 kw. Primary Turbine Generator, speed 3,000 r.p.m.*

The relationship between the blade-speed ratio and the dimensions of the machine may be derived as follows :—

Let D=mean dia. of blade ring in inches. Let N=number of revolutions per minute. Let H=total energy available by expansion in B.Th.U. per lb. Let n=number of stages. Let ρ=blade speed ratio. Let u=blade velocity in feet per second. Let V_1 = initial velocity of steam issuing from the nozzles in feet per second. Let h= energy available in any one stage.

$$\text{Then } u = \frac{\pi D}{12} \times \frac{N}{60} = \frac{DN}{229}, \text{ and } V_1 = \sqrt{2g.\ J.\ h} = \sqrt{2g.\ J.\ \frac{H}{n}}$$

$$= 224 \sqrt{\frac{H}{n}}$$

$$\text{Now } \rho = \frac{u}{V_1} = \frac{DN}{229} \cdot \frac{1}{224} \sqrt{\frac{n}{H}} \quad \text{or } \rho = \sqrt{\frac{n \left(\frac{D}{10}\right)^2 \cdot \left(\frac{N}{100}\right)^2}{2620\ H}} \quad \textit{i.e.}, \rho = \sqrt{\frac{K}{2620\ H}}$$

$$\text{where } K = n \cdot \left(\frac{D}{10}\right)^2 \left(\frac{N}{100}\right)^2$$

K is the well-known Parsons coefficient. Since the efficiency of the blading is a function of ρ, and since H varies widely in practice, the writer in his book* has suggested that the quantity $\frac{K}{H}$ connecting the "dimensions" of the turbine and the total heat drop be called the "efficiency factor." Although the brake efficiency ratio, *i.e.*, the ratio of the brake horse-power at the coupling to the theoretical horse-power based on the weight of steam per second and the adiabatic heat drop is not strictly a function of ρ owing to the variable influence of losses, a fair idea of the performance of modern steam turbines may be obtained by plotting efficiency ratio against values of the efficiency factor. A few such values are shown in Fig. 10.

The total cost of a steam turbine is made up mainly by two classes of items, viz. :—

(*a*) Those more or less independent of the choice of mean diameter and of number of stages, *e.g.*, bearing blocks, governor gear, steam valves and piping, bedplate, exhaust belt and exhaust branch.

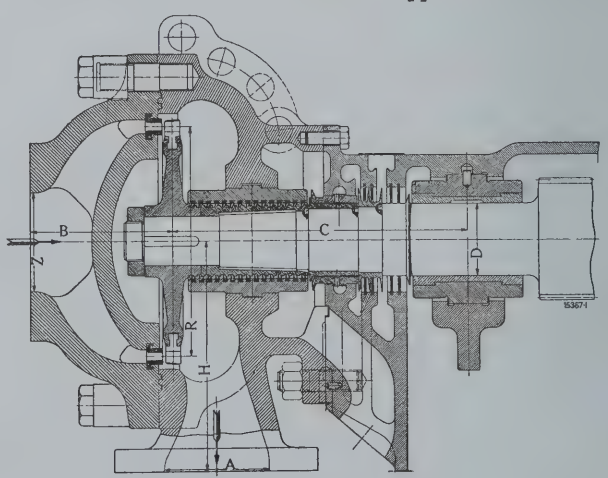


FIG. 13.

* "Steam Turbine Theory and Practice."

(*b*) Those whose cost is dependent on the choice of n and D, such as the casing, discs, blading, diaphragms and spindle.

The cost of items (*b*) will vary roughly as the product $n D^2$ or the sum of the products $\Sigma n D^2$, and the total cost of the turbine will be roughly, $C = A + B (\Sigma n D^2)$, where A and B are constants.

It is clear, therefore, that a high value of $\frac{K}{H}$ which is necessary for high efficiency, is, for any given rotational speed N, associated with a relatively high cost. It is in this connection that the choice of rotational speed is of the utmost importance, for if K be made constant, then the second term in the cost equation becomes inversely proportional to the square of the rotational speed.

Disadvantages of High Speeds. The capacity of steam turbine units has steadily increased during the past twenty years from about 3,000 kw. to 30,000, and even 50,000 kw. In one instance, 50,000 kw. is being developed in a single casing. At the present time, a " unit " of 208,000 kw. is under construction in the United States. The selection of a high rotational speed necessarily results in a reduction of mean diameter for any given upper limit of peripheral speed. Nozzle heights must be reduced in a similar proportion, and if the rotational speed in one design is twice that in another, then other things being equal, the maximum output of the first machine will only be one-fourth that of the second. The reduction of steam way caused by the adoption of a high rotational speed imposes serious limits to the capacity of a turbine, especially in a high vacuum job.

This practical drawback of high speeds may be surmounted in various ways, of which the following are some :—

(*a*) By the adoption of a double-flow low-pressure turbine. This is frequently adopted in large Parsons turbines.

(*b*) By means of a divided flow at the exhaust end of the turbine. Fig. 11 shows an example of this. Up to the eleventh stage, the machine is an ordinary impulse turbine. After this point, about one-half of the steam flows through three wheels, whose blades have approximately the same mean diameter as the preceding stages. The steam passes into a volute chamber B, and finally into the exhaust branch C. The other half of the steam flows into a chest E, which is also of volute form, and is expanded through two stages of somewhat larger mean diameter.

(*c*) By the adoption of the " multi-exhaust " system devised by K. Baumann.

(*d*) By running the low-pressure machine at a lower speed than the high-pressure end, using two or more lines of shafting. The turbines are coupled to alternators in parallel, but running at different speeds. A recent example of this type of installation is the 50,000 kw. Parsons set in the Crawford Avenue Station, Chicago. The following are the relevant particulars :—

Turbine.	Speed R.P.M.	Power KW.	No. of Poles on alternator rotor.	Frequency.
H.P.	1,800	15,000	4	60
I.P.	1,800	30,000	4	60
L.P.	720	5,000	10	60

(*e*) Some advantage in this respect may be obtained by bleeding the main turbine for feed heating purposes. This has already been mentioned under *The Regenerative Steam Cycle.*

Special Conditions imposed by High Steam Pressures. A potential source of loss in steam turbines operating with high-pressure steam is the so-called " rotation loss."

This is comprised of two separate losses, the " disc friction " loss and the " vane action " loss.

The latter is only present in those stages of the turbine in which the nozzles do not extend completely round the circumference. It may be reduced by suitably encasing the moving blades in the inactive segments of the ring, but it is best prevented by diminishing the nozzle height until the nozzles extend completely or almost completely around the circumference.

The so-called " disc friction " loss is partly due to true surface friction, but mainly due to fan action produced by frictional entrainment of the steam. From a consideration of the latter action it may be shown that the power loss is probably represented by an equation of the form $H.P_d = C.\ D.^5\ N^3\ \rho_s$., where D = mean diameter of blade ring (inches); where N = R.P.M.; where ρ_s = steam density in lb. per cubic foot; where C = a constant.

This is borne out by experiment, the value of the constant being in the neighbourhood of 3.5×10^{-17}.

When high-pressure steam is used and, particularly, when all stages are single-row pressure-compounded (as they frequently are in large units), the steam density is high and the disc friction loss may be excessive. Some idea of the magnitude of this important loss may be formed by an inspection of the figures in Table III.

Here, the blade speed has been assumed constant, and provided the ratio of blade speed to steam speed be made the same in all cases, the " appetite " for energy, *i.e.*, the heat drop that can be utilised, is constant. This table, then, shows merely the influence of steam density and rotational speed.

TABLE III.—DISC FRICTION LOSSES IN STEAM TURBINES.

Calculated by means of the equation $H.P_d = 3.5 \times 10^{-17}.\ D^5.\ N^3.\ \rho_s$.

Mean blade velocity constant at 600 ft./sec. Steam condition assumed dry and saturated for simplicity.

Steam Pressure in stage, lb./sq. in. abs.	Steam Density lb./cu. ft.	Horse-power lost in disc friction per stage.		
		At 1,500 R.P.M.	At 3,000 R.P.M.	At 6,000 R.P.M.
1,000	2.27	1,732	433	108
500	1.08	824	206	51
200	0.437	333	83	21
100	0.226	172	43	11

If we select lower blade speeds as shown in Table IV., we find that the disc friction horse-power, *per stage*, is considerably reduced, but it must be remembered that a reduced blade speed involves a reduced steam speed and, of course, a smaller stage heat drop.

TABLE IV.—DISC FRICTION LOSSES IN STEAM TURBINES WITH A CONSTANT ROTATIONAL SPEED OF 3,000 R.P.M., AND WITH VARYING PERIPHERAL VELOCITIES.

Calculated by means of the equation $H.P_d = 3.5 \times 10^{-17}.\ D^5.\ N^3.\ \rho_s$.

Steam Pressure in stage, lb./sq. in. abs.	Steam Density lb./cu. ft.	Horse-power lost in disc friction per stage.					
		Mean blade speed in feet per second.					
		100	200	300	400	500	600
1,000	2.27	.06	1.78	13.52	56.8	174.5	433
500	1.08	.03	.84	6.43	27.0	83.0	206
200	0.437	.01	.34	2.60	10.9	33.6	83.5
100	0.226	.006	.18	1.35	5.65	17.4	43.1

Consider a single stage, in which the blade velocity is 600ft. per second. With a favourable ratio of blade speed to steam speed and a nozzle efficiency of 87 per cent., the heat drop in the nozzles would

be 35.7 B.Th.U. per lb. Other things being equal, the heat drop corresponding to a mean blade velocity of 300ft. per second would be only 8.925 B.Th.U. per lb., and four such stages would be required to replace the one having a blade speed of 600ft. per second. For simplicity, consider the same steam density, namely 1.08 lb. per cubic ft., corresponding to a stage pressure of 500 lbs. With a blade speed of 600ft. per second the loss is 206 H.P., and with $u = 300$, the loss is 4×6.43 or only 25.7 H.P. This necessarily brief consideration of the problem shows that in order to obtain a reasonably high efficiency ratio in super-pressure turbines, a relatively large number of small diameter wheels must be used.

An interesting application of this principle is illustrated in Fig. 12, which shows a 10,000-kw. super-pressure "primary" turbine. It comprises an alternator running at 3,000 R.P.M. and four small turbines in series, each driving the alternator through speed reduction gearing. A sectional view of such a primary turbine is shown in Fig. 13. There is one stage, the initial pressure is 800 lb. per sq. inch, and the power developed in the unit illustrated is about 1,500 kw. It may be stated, in passing, that the conversion of an existing steam station to a super-pressure station may be effected by the installation of high-pressure boilers supplying steam to the primary turbines which are then designed to exhaust into the ordinary steam main of the station, or preferably, into reheaters coupled to the main steam pipe.

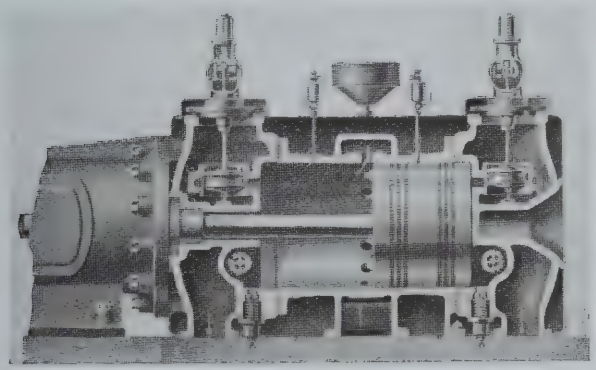


FIG. 14.

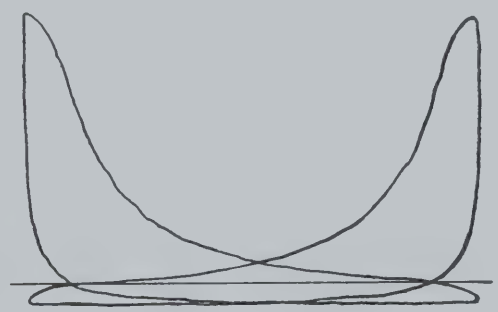


FIG. 15.—*Indicator diagrams from Uniflow Engine.*

In recent designs of large units there are two turbines in tandem, (1) a high-pressure unit with small discs, low steam velocities, accurately machined nozzles, a small compact casing, lower stresses in diaphragms and a relatively small spindle with consequently reduced leakage losses; and (2) a low-pressure turbine following the usual lines.

RECENT DEVELOPMENTS IN STEAM ENGINE PRACTICE LEADING TO ECONOMY OF FUEL.

Use of Higher Pressures. It is almost a century since Perkins suggested the use of very high steam pressures in reciprocating engines. Various attempts were made from time to time to adopt these suggestions, but with little success, for engineering science was not sufficiently advanced to make it possible.

In recent years the bulk of the experimental work has been done in Germany, chiefly, by the late Dr. Wilhelm Schmidt. The outcome of the experiments was to show, quite definitely, that, in order to get the best results, the super-pressure steam must be highly superheated in the first place, and must be re-superheated once or twice between the cylinders. Some of the numerous experiments were conducted on a quadruple-expansion engine of only 150 H.P. In the first tests, the *indicated* thermal efficiency was 24.5 per cent. for the engine only. By re-superheating, the indicated thermal efficiency was raised to 30.7 per cent. Assuming a mechanical efficiency of 92 per cent., and a boiler efficiency of, say, 78 per cent., the possible brake thermal efficiency of such a high-pressure plant is no less than 22 per cent.

On the practical side, little difficulty appears to have been experienced. Pistons and stuffing boxes worked better than was expected. Piston valves appeared to be the most suitable for this work. It is

considered that no difficulty is likely to be met when ordinary grades of lubricating oil are used in the high-pressure cylinders, even with very high superheats, owing to the raising of the boiling point of the oil by the high steam pressure. Reheating may be carried out by superheated or saturated high-pressure steam. In Schmidt's experiments the latter method was used.

The Uniflow Engine. One of the most notable developments of recent years is the "uniflow" engine. Strangely enough, this, too, was foreshadowed by an Englishman and made a practical success by the labours of a German. In 1885, J. L. Todd took out a patent in Great Britain for a double-acting steam engine, in which steam was admitted by valves at each end of the cylinder and exhausted through ports in the centre of the cylinder. However, owing to difficulties caused by the high compression, Todd's patents came to nothing. Many years after, about 1908, an engine on the same lines was designed by Professor J. Stumpf, of Charlottenburg. Considerable success was realised almost immediately, and the manufacture of the engine was taken up by many Continental firms.

The chief constructional features of the uniflow engine are illustrated in Fig. 14. There is a plain cylinder barrel without a steam jacket and having a ring of exhaust ports communicating with an exhaust belt. There are two steam admission valves fitted in the end covers which form, simultaneously, steam chests and steam jackets. The piston is unusually long, being equal to about 90 per cent. of the stroke. It controls the release of steam from either end.

The action is fairly obvious. Steam is admitted through the admission valve up to about 10 per cent. of the stroke at full load. Governing is usually effected by varying the point of cut-off. After cut-off, the steam expands to a pressure slightly less than atmospheric, when release occurs. On the return stroke, after exhaust is completed, the piston covers the exhaust ports and the steam trapped in the cylinder is compressed to a pressure which depends on the exhaust pressure. Typical indicator diagrams are shown in Fig. 15.

Broadly speaking, the flow of steam through the working cylinder at each end is uni-directional, hence the name "Uniflow." Herein, lies the chief advantage of this type of engine on a thermal basis. The admission end of the cylinder is hot, the centre of the cylinder barrel is comparatively cool, and experiments have shown that there is gradual temperature gradient from the ends of the cylinder to the centre. Owing to the absence of exhaust valves in the cylinder ends, the clearance volume may be greatly reduced; likewise the clearance surface and the various losses caused by clearance. The actual clearance volume is from $1\frac{1}{2}$ to 3 per cent., as compared with about 6 per cent. in H.P. and 6 to 10 per cent. in L.P. engines of ordinary design. The high compression is probably beneficial, for the entrapped steam is compressed to a fairly high pressure and temperature, so that the amount of heat absorbed from the incoming steam will be less than with a much lower compression. During expansion, it is highly improbable that the temperature of the whole mass of steam in the cylinder is uniform. That near the piston will be colder than that which is in contact with the hot cylinder ends, and during the exhaustion period it will be expelled first. Thus the steam which is compressed is the hottest steam present in the cylinder, and this fact helps to minimise heat losses and also to maintain the cylinder barrel temperature at a somewhat higher value.

The thermal efficiency of the uniflow engine is better than that of compound engines, and equal to the best triple-expansion engines operating between the same limits of pressure.

There are some disadvantages peculiar to this engine. Owing to the high compression ratio, very high compression pressures would be reached in the event of starting with atmospheric exhaust, or of a breakdown of the air pump. Some device must, therefore, be fitted to relieve this excessive pressure. In some designs an additional clearance space is provided in the cylinder covers. When the exhaust pressure rises, through any cause, valves are automatically opened which unite the cylinder with the additional clearance space.

For successful operation, it is essential that the uniflow engine be operated continuously in the one direction. It is thus specially suitable for driving textile, paper, tin-plate and sheet mills and, also, for driving electric generators.

The piston loads in a uniflow engine are about twice those in a tandem compound, and nearly three times those in a cross-compound engine of the same power and same initial pressure. The working parts require to be heavy, and demand care in design and construction.

THE ECONOMICAL UTILISATION OF STEAM IN POWER AND HEAT PLANTS.

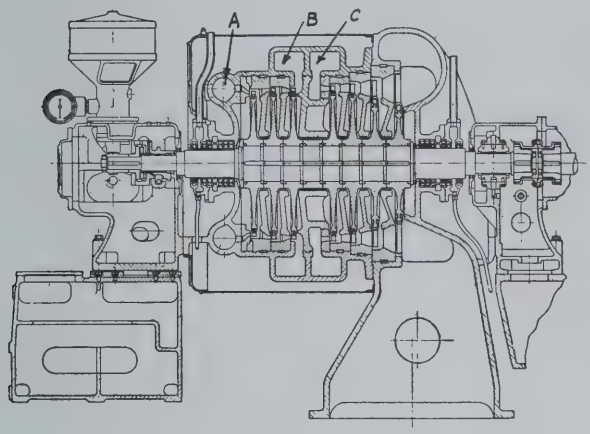


FIG. 16.—*Steam Extraction Turbine.*

Every engineer connected with steam power plants realises the inevitable, but regrettable, loss of heat to the cooling water. In a good plant, of every 100 heat units supplied in the fuel, about 20 are lost up the stack and about 64 pass into the cooling water. In industrial processes in which there is a dual demand for power and heat, this waste may be largely prevented, by generating steam in boilers at a fairly high pressure, expanding it through engines or turbines to a pressure suitable for heating purposes, and utilising the large amount of latent heat for heating purposes. From the thermal point of view, the pressure at which the steam is generated should be as high as circumstances will permit, and the pressure at which the heating steam is exhausted from the engine should be no higher than necessary.

Two distinct types of plant are in use for this class of work.

Back Pressure Machines. When there is a definite relationship between the steam required for power purposes and that required for heating, a simple back-pressure engine or turbine may be installed.

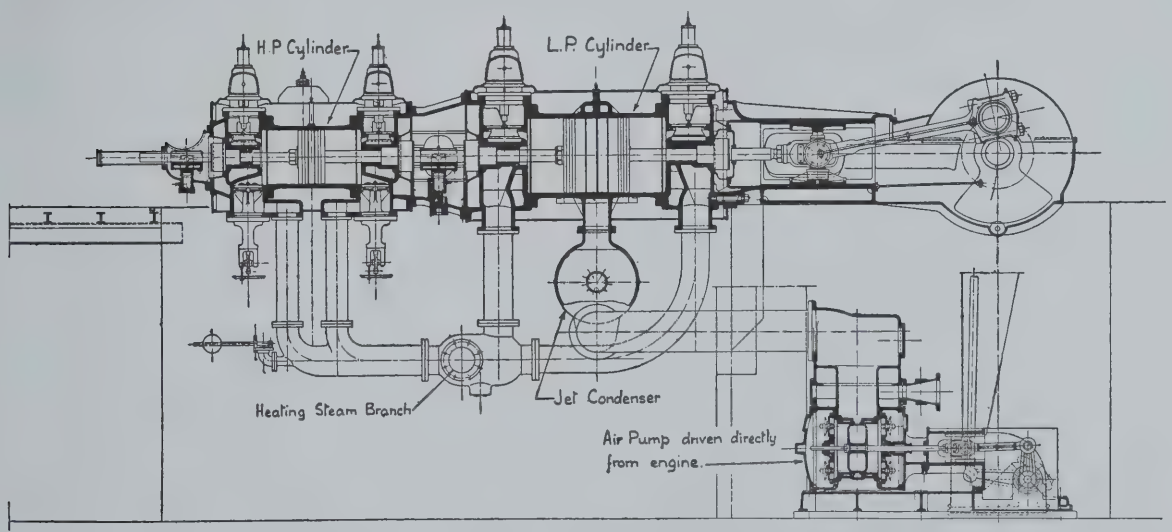


FIG. 17.—*Horizontal Tandem Steam Extraction Engine.*

If, for short periods, the heating steam is not required, or if the demand falls off, the exhaust steam from the prime mover may be sent into the atmosphere or into some form of heat accumulator. This is a very simple and relatively cheap type of plant.

Heat Extraction Machines. It frequently happens that there is no similarity between the amount of steam required for power and heating purposes. When this is the case and, especially, when the weight of steam required to generate the required power is much in excess of that necessary for heating, the installation of a simple back-pressure engine is wasteful. By adding a low-pressure cylinder to the engine, or further low-pressure stages to the turbine, a greatly increased economy can be effected.

Considerable developments have been made in this class of engine within the last few years. The following conditions must be observed :—

(1) The engine or turbine speed must be kept sensibly constant, irrespective of change of load or of heating steam demand.

(2) The heating steam pressure must be kept sensibly constant under all conditions.

These conditions are fulfilled by the use of two governors, (*a*) *a speed governor*, which regulates the point of cut-off in the high-pressure cylinder in steam extraction engines, and which regulates the supply of steam to the whole machine, in the case of steam extraction turbines, and, (*b*) *a pressure governor*, under the influence of the heating steam pressure, which controls the point of cut-off in the low-pressure cylinder of the engine, and which controls the lift of a by-pass valve between the two sections of the turbine. In both classes of prime mover, this combined speed and pressure governing system is giving satisfaction.

Steam extraction engines and turbines should be designed specifically for a clearly defined duty if the best results are to be obtained. Such a remark is true of every engine, but it is especially true in this instance.

A high-speed, geared, steam extraction turbine is shown in Fig. 16. High-pressure steam is admitted to the chest A, and expanded through the three stages of the H.P. section. It then enters the belt B, from which that steam required for heating is withdrawn. The remainder of the low-pressure steam is by-passed into the belt C, and does work in the four low-pressure stages of the turbine.

An example of a steam extraction engine is illustrated in Fig. 17. It comprises a high-pressure counterflow engine fitted with four drop valves, and a low-pressure uniflow engine, in tandem. Heating steam is extracted from the receiver between the high-pressure and low-pressure cylinders. That steam which is not required for heating purposes is further expanded in the low-pressure cylinder, performing useful work therein. Whatever the conditions of power load and demand for heating steam, the cut-off in the low-pressure cylinder is never allowed to fall below a certain minimum value. On a light power load and a relatively heavy heating load, as this minimum cut-off is approached, a special by-pass valve supplies live steam to the heating main.

The heat extraction machine represents the practical solution to a problem which arises in many industries, and above all, it is a solution which leads to a considerable economy of fuel.

Chapter 5.

WATER SERVICE IN POWER GENERATION.

By T. Roland Wollaston, M.I.Mech.E.

In inaugurating any scheme involving the generation of steam power, consideration of water supply is almost as important as considerations of fuel supply—in some cases even more important. Fuel can always be obtained at a price. Water in sufficient quantity may be very difficult to secure, and sites for new works, often possessing every other desirable feature, may be turned down because the cost of obtaining an adequate flow to and from the power house is prohibitive.

The greatest demand is, of course, in connection with condensing in steam installations, and total volumes of the order of five million gallons per hour may have to be provided for the modern super-power station. Fortunately, for such service, quality may be regarded as a secondary consideration, quantity and temperature being the main factors. The water will be taken into the station at temperatures ranging from 30° F. in winter to 70° F. in summer, and will generally be discharged or returned slightly above or below 100° F. Obviously, when drawn from a river, dock or like source, the points of intake and outlet must be widely separated and so located that the natural flow tends to carry the hot water away, to maintain constantly the lowest possible temperature at the intake.

There are, in large power-station work, many cases in which return temperatures approximating 100° cannot be contemplated; where, indeed, a rise of 10° or 12° between intake and outlet is the highest permissible. In modern steam-turbine practice high vacua are essential if high efficiency is to be secured. Immense volumes of water must therefore be put through the condensers. In the case of reciprocating condensing engines, when vacua of 25in. or 26in. are high enough, the average allowance of condensing or circulation water, reckoned as between 60° F. average intake temperature and 110° outlet, is about thirty times the amount of feed water. In some modern power stations when vacua of the order of 29in. are desirable and outlet temperatures exceeding 80° are prohibited, the circulation water may exceed one hundred times the amount of feed water.

We have stated that " quality " is a secondary consideration, but it is not one which can be ignored altogether. Some supplies, dock waters in particular, have violently corrosive properties. Few problems in engineering have induced more research or have remained so difficult of solution as that of condenser tube wastage, following the circulation of corrosive condensing water. Leaking condenser tubes allow access of circulation water to the boiler-feed system and may lead to endless trouble.

The employment of the surface condenser may be regarded as universal in large installations, because, if well maintained, it provides the surest means of obtaining perfect feed-water for the boilers. In smaller installations located near to river, lake, or the like providing reasonably pure water in abundance, the jet condenser is still favoured for small and moderate powers, some portion of the overflow being withdrawn and possibly put through a process of softening, de-greasing, or de-oxygenating for boiler feed.

The advent of the steam turbine has considerably simplified the feed-water problem, in that the condensate therefrom is always substantially grease free; but reciprocating engines are, and will continue to be, used largely in many departments of industry, chiefly as high-pressure units passing out their exhaust steam for process work, and the condensate should, when possible, be collected for boiler feed. Probably no feed-water contamination is so objectionable and dangerous as that of oil or grease in emulsion, and it is becoming daily more common to run reciprocating engines, steam pumps, and the like with greatly reduced cylinder lubrication, or even without any more oil than enters the cylinder as the result of swabbing piston rods. This subject will be treated more fully later.

When abundant supplies of condensing water are not available from natural sources, the alternative is the continued circulation of the same water over cooling towers. More than one case has been instanced in which, with abundant supply of sea, river, or dock water within reasonable distance, the cooling tower system has been selected as involving lower capital outlay for the same effect. The outstanding objections to cooling-tower systems are, in large installations, the ground space required and their unsightliness.

The normal natural-draught cooling tower, a familiar sight in most industrial areas, is so designed that an upward current of air meets and comes intimately in contact with the falling hot water. The air, on coming into contact with the hot water, has its absorption capacity increased. A part of the water is evaporated and is lost as vapour. This evaporation is the chief factor in the cooling action, a secondary factor being the cooling by actual contact of the hot water with the air. The loss of water by evaporation has necessarily to be made good. The hot water on entering the main cooler trough, usually at some 20 feet above ground level, is distributed over the whole area of the tower and falls from nozzles upon special splash plates arranged to break up the water thoroughly into sprays. The sprays fall on to a labyrinth of timber laths which further break up and film the water particles, ensuring maximum contact with the air current. In cases where there is limited available ground space, or where a constant cooling effect is necessary in any description of climate, the forced-draught type of cooler is used, employing a fan to regulate the supply of air. The principle of action is similar to that of the natural-draught type. The fan may be either of the forced-draught type, delivering air to the bottom of the cooler, or of the induced type drawing the air from the top. The hot water falls through the cooler, being intercepted by a " filling " composed of non-corrodible metallic screens which serve to break up the water into small particles. The cost of operating fans has to be considered, but the advantages of compactness, positive action, and low temperature attainable, may easily become the deciding factor in the choice of this type of cooler.

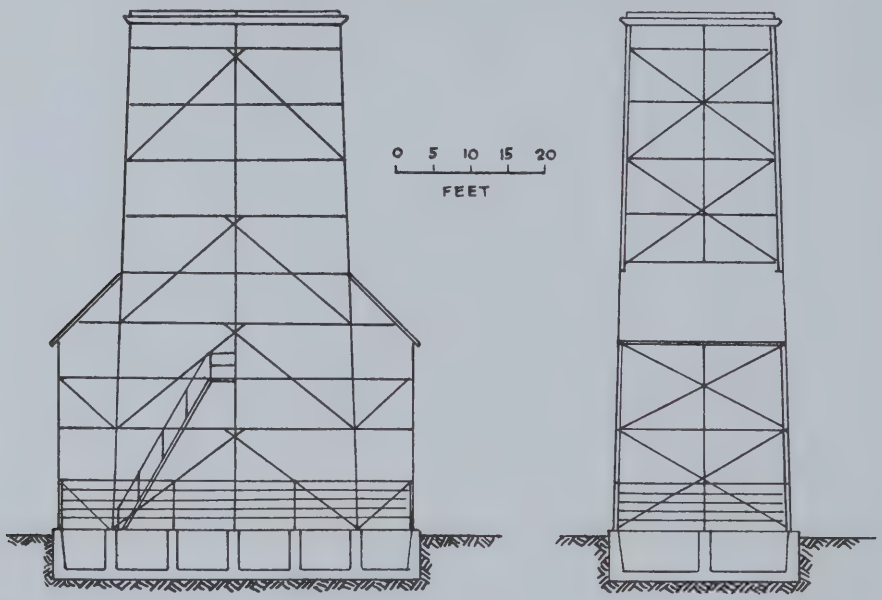


Fig. 1.

In designing cooling tower installations of ordinary size it is usual to assume that the loss of cooling water due to evaporation, leakage and the like, to be made up from some external source, will be 10 per cent. of the total water circulated; but recent large scale plants are working on less than half this amount.

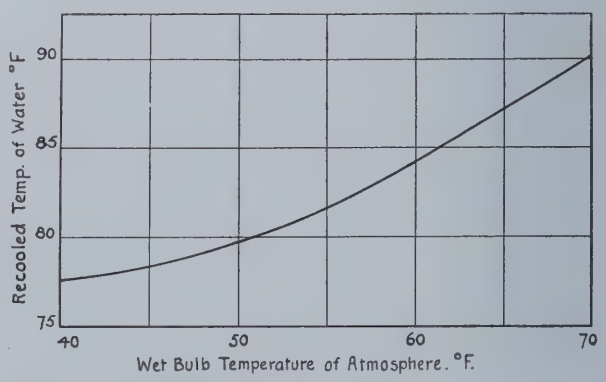


Fig. 2.

The illustration (Fig. 1) shows to scale a natural-draught cooling tower over a concrete tank, which is capable of dealing with 10,000 gallons of water per hour to reduce from 100° to 80° F. with an air temperature of 55° F. and humidity of 75 per cent. The graph (Fig. 2) indicates the re-cooled temperature which would be obtained with this tower with varying atmospheric conditions, based upon wet bulb temperature, assuming constant circulation and a constant temperature difference of 20° F. The following table provides a fair perspective of the proportions of such plant of different types for various duties:—

WATER COOLING PLANT.

To cool from 100° F. to 80° F., under average atmospheric conditions experienced in this country.

Galls. per hour.	Open Type. Height. Ft.	Open Type. Ground area. Sq. ft.	Chimney Type. Height. Ft.	Chimney Type. Ground area. Sq. ft.	Fan Draught. Height. Ft.	Fan Draught. Ground space. Sq. ft.
10,000	18	390	60	192	30	140
20,000	18	630	60	352	30	220
50,000	18	1,300	70	730	40	400
100,000	18	3,000	70	1,300	40	620
500,000	18	16,000	70	5,600	40	2,700

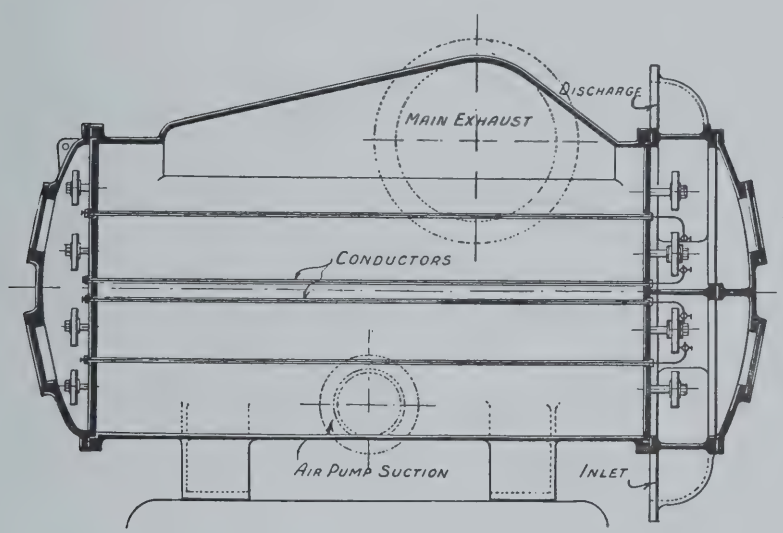


FIG. 3.

Reference has been made to the wastage of condenser tubes and its deleterious, even dangerous, effects in permitting impure cooling water to have access to the boiler feed. Such wastage is generally of the nature of pitting and is clearly electrolytic in character, which is not surprising when one recognises the number of different metals with which the condensing water comes in contact and the foul sources from which it is often drawn. Probably no branch of metallurgy has been more closely studied by engineers than that of condenser tubes. Formerly brass tubes tinned upon the surfaces were used. These have been superseded by various alloys, but it is now generally recognised that no process of manufacture can prevent such wastage entirely, and that the right line of investigation is removal of the cause.

Probably the most successful, at any rate the most hopeful, means so far adopted has been that of mounting upon insulated studs from the tube plates, masses of some suitable metal which is electro-positive to the alloy of which the tubes are made, and connecting these by wires to the points at which corrosion does, or is most likely to, occur. The corrosion is then transferred from the tubes and tube plates to the added metal which can be readily replaced as necessary. A condenser thus fitted is illustrated in Fig. 3. It is imperative, for such apparatus to be effective, that there should be better metallic contact than the usual ferrule and asbestos packing gives, at the ends where the tubes pass through the tube plates.

It may be safely stated that no available natural source provides pure water. Even collected rain water in this country shows hardness or acidity gathered from the atmosphere in industrial centres, and to no inconsiderable degree. Deep well waters, usually organically very pure, are generally "hard"; that is to say, they carry in solution considerably quantities of salts of calcium and magnesium, in the form of bi-carbonates, sulphates, nitrates, nitrites and chlorides. Water from wells passing through limestone and marl measures is almost invariably hard. From wells in granite and sandstone districts it is generally less hard.

River waters may show widely varying results on analysis, dependent upon their source and the country through which they flow, while from canals, docks, and the like we find in conjunction with the

mineral matter of the original source the organic contamination of sewage and of effluent from industrial undertakings. Water from coal measures has frequently very deleterious mineral impurities. In some cases known to the writer pit waters have held more chlorides in solution than sea water.

Modern steam plant, involving high pressures, with boilers and condensers having enormous tube surface, has brought prominently and uncomfortably to the notice of engineers two causes of potential trouble which were regarded as of little importance twenty years ago. These are emulsified oil and dissolved oxygen. The former is less in evidence as the reciprocating engine is superseded by the steam turbine, but there is no doubt that it is still the origin of many failures of boiler tubes through overheating. Stromeyer, who has carefully studied this subject, says that, "As grease offers ten times more resistance to heat (than scale) one would expect that $\frac{1}{80}$in. would have the same effect as this ($\frac{1}{8}$in.) thickness of scale, but experience shows that the merest trace of grease, certainly less than $\frac{1}{1000}$in., can cause far more serious injury than scale. Various explanations have been attempted. According to one of these, thin films of grease form tough bubbles on the heating surface and prevent the water from keeping it cool. Another view is that grease, either alone or joined to mineral matter, forms an impalpable powder like oxalate of lime and other precipitates and, like these, retards ebullition." Later Stromeyer places the critical pressure at or above which greasy feed water becomes troublesome at 110 lbs. per sq. in.

Concentration of Soluble Salts. The experience of the last few years has shown the necessity of guarding against concentration of salts highly soluble in water, as for example sulphate of sodium and the chlorides of sodium and magnesium. It is suggested by Stromeyer that whereas Lancashire boilers may be worked safely with water containing 4 or 5 per cent. of soluble salts, water tube-boilers with some of their tubes exposed to intense radiant heat should not carry water with density from soluble salts exceeding 1 per cent. He further states that while Lancashire boilers evaporate their water content in about five hours, some water-tube boilers do so in one hour. Therefore, when using water containing soluble salts, water-tube boilers should be blown off frequently. These soluble salts are known to deposit, under certain conditions, long before the point of saturation of the general volume is reached, due to the rapid formation of steam bubbles in contact with surfaces exposed to intense radiant heat.

The following table gives the solubilities of salts as they occur in waters used for boiler feed:—

SOLUBILITY OF VARIOUS SALTS IN PURE WATER AT 60° F.
(Parts of Anhydrous Salt per 1,000 parts of water).

Calcium Sulphate	1.970	Magnesium Hydroxide	0.009
Calcium Carbonate	0.013	Magnesium Chloride	541.000
Calcium Hydroxide	1.690	Magnesium Nitrate	727.000
Calcium Chloride	660.000	Silica (SiO_2)	0.003
Calcium Nitrate	548.000	Sodium Carbonate	168.00
Magnesium Sulphate	333.000	Alumino-Ferric (as Aluminium Sulphate)	350.00
Magnesium Carbonate	0.200 (53.6° F.)	Sodium Sulphate	138.00
		Sodium Chloride	359.00

Recent experience and research have thrown much light upon the subject of corrosion and pitting in boilers. Evenly distributed corrosion was, only a few years ago, generally attributed to direct chemical action resulting from acidity in the water, but was found somewhat difficult to explain when occurring on constantly wetted surface and in the presumed absence of oxygen. Local corrosion and pitting were somewhat vaguely regarded as the result of electrolytic action in which the boiler becomes a cell and the steel of the affected parts the positive element. Later it was realised that, of the main constituents of air, nitrogen and oxygen, the latter is much the more soluble in water, and is, in all natural supplies, present in sufficient quantity to account for most corrosive effects found. Recent careful observation appears to indicate that in practice air or oxygen of itself does not set up corrosion.

The following views are quoted from a paper read by Weir at the Hague in 1923:—

1.—Pure water is chemically inert with regard to steel or iron throughout the whole temperature range of modern boiler practice, provided no other materials, either gaseous or liquid, are present.

2.—Water containing air in solution is chemically inert with regard to steel, provided the temperature and pressure conditions are such as to maintain the air in solution.

3.—If air be liberated from solution in water by raising the temperature or lowering the pressure of the latter, the oxygen thus liberated combines directly with iron, forming iron oxide (FeO). Iron oxide forms a hard, adhesive, and protective coating, and stops further action.

4.—If the reaction indicated in (3) takes place in the presence of CO_2, the latter combines at once with the FeO, forming Fe_2CO_3. This is soluble and is in turn oxidised by any oxygen present in the water, liberating the CO_2 and permitting continuous corrosion to take place.

So much has been written in recent technical publications regarding scale forming waters that the subject may here be dealt with very briefly. The following is a list of the mineral constituents found in natural water supplies:—

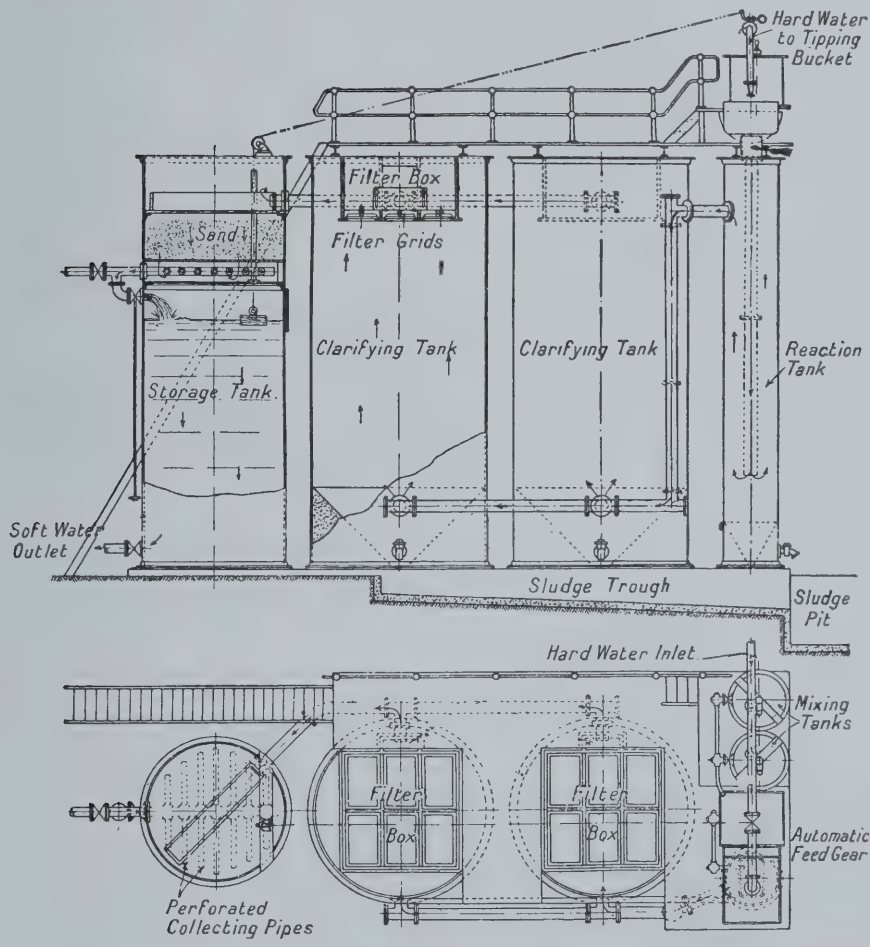


FIG. 4.

SCALE FORMING.

Calcium—	
Sulphate	$CaSO_4$
Carbonate	$CaCO_3$
Silicate	$CaSiO_3$
Magnesium—	
Hydrate	$Mg\ O_2H_2$
Carbonate	$Mg\ CO_3$
Silicate	$Mg\ SiO_3$
Ferric Oxide—	Fe_2O_3

NON SCALE-FORMING.

Sodium—	
Nitrate	$Na\ NO_3$
Chloride	$Na\ Cl$
Sulphate	Na_2SO_4
Carbonate	Na_2CO_3
Bi-Carbonate	$Na\ H\ CO_3$
Silicate	$Na_2\ Si\ O_3$
Hydrate	$Na\ HO$
Calcium—	
Nitrate	$Ca\ (NO_3)_2$
Chloride	$Ca\ Cl_2$
Magnesium—	
Nitrate	$Mg\ (NO_3)_2$
Chloride	$Mg\ Cl_2$
Sulphate	$Mg\ SO_4$

"Hardness" in water may be described and measured as the power of its dissolved mineral matter to destroy soap. It is often classed under two headings:—

Temporary hardness caused by dissolved salts which become insoluble and precipitate out when water is raised to and maintained at 212° F. (or often below this temperature). *Permanent hardness* which only salts out by heat at higher temperatures and at pressures considerably above atmospheric.

The chief causes of temporary hardness are the carbonates of calcium and magnesium existing as bi-carbonates in combination with carbonic acid. In water softening they are treated by admixture of milk of lime or lime-water. The added lime combines with the carbonic acid, leaving the original and added calcium and magnesium in the form of the practically insoluble carbonates which precipitate out. The reactions expressed as chemical formulae are:—

$$\underset{\text{(Soluble)}}{Ca\ H_2\ (CO_3)_2} + \underset{\text{(Soluble)}}{Ca\ O} = \underset{\text{(Insoluble)}}{2\ Ca\ CO_3} + \underset{\text{(Water)}\frac{1}{2}}{H_2O}$$

PRIMARY REACTION.

$$\underset{\text{(Soluble)}}{Mg\ H_2\ (CO_3)_2} + \underset{\text{(Soluble)}}{Ca\ O} = \underset{\text{(Slightly soluble)}}{Mg\ CO_3} + \underset{\text{(Insoluble)}}{Ca\ CO_3} + \underset{\text{(Water)}}{H_2O}$$

SECONDARY REACTION.

$$\underset{\text{(Slightly soluble)}}{Mg\ CO_3} + \underset{\text{(Soluble)}}{Ca\ O} + \underset{\text{(Water)}}{H_2O} = \underset{\text{(Insoluble)}}{Mg\ (OH)_2} + \underset{\text{(Insoluble)}}{Ca\ CO_3}$$

Reduction of temporary hardness by lime is possible down to a point at which Ca CO_3 becomes soluble, say, something between 1 and 2 grains per gallon, but the softening down to this degree is chemically satisfactory in that the hardening salts are precipitated and wholly removed, not merely replaced by soluble salts. To this extent water softening may be regarded as practically equal to distillation.

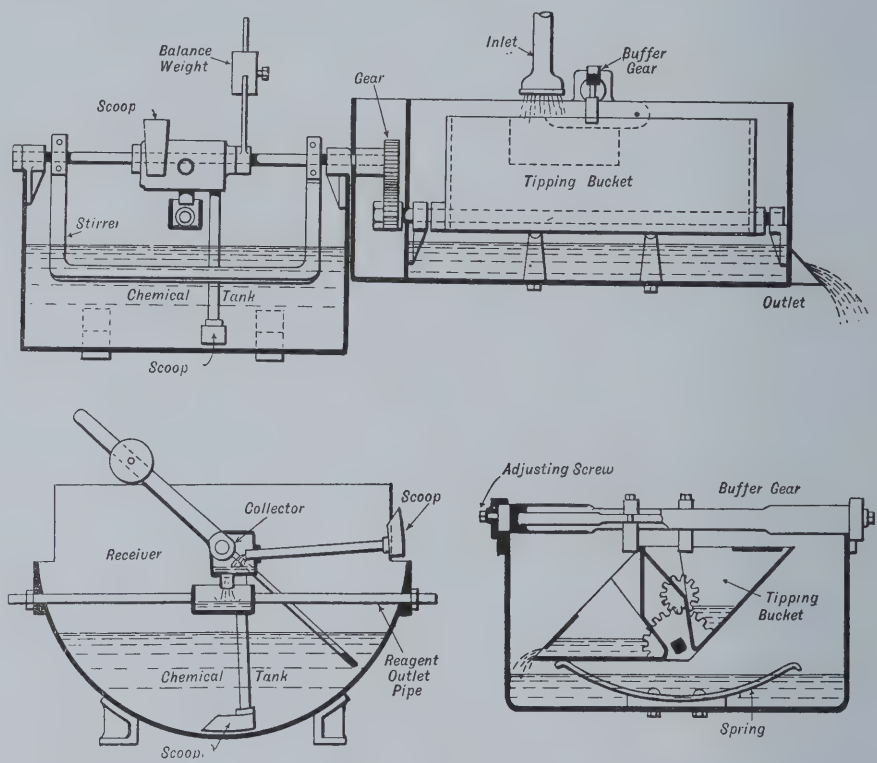


FIG. 5.

The most common causes of permanent hardness are the sulphates of calcium and magnesium which, in water softening, are generally treated by the addition of sodium carbonate. The reactions are :—

$$\underset{\text{(Soluble)}}{Ca\ SO_4} + \underset{\text{(Soluble)}}{Na_2\ CO_3} = \underset{\text{(Insoluble)}}{Ca\ CO_3} + \underset{\text{(Soluble)}}{Na\ SO_4}$$

$$\underset{\text{(Soluble)}}{Mg\ SO_4} + \underset{\text{(Soluble)}}{Na_2\ CO_3} = \underset{\text{(Slightly soluble)}}{Mg\ CO_3} + \underset{\text{(Insoluble)}}{Na\ SO_4}$$

And a secondary reaction as above:—

$$Mg\ CO_3 + Ca\ O{=}H_2\ O = Mg\ (OH)_2 + Ca\ CO_3$$

It will be noted that the treatment for permanent hardness leaves sodium sulphate, a highly soluble, but in ordinary cases harmless salt, in solution, the concentration of which may, in modern water-tube boiler practice, be troublesome, even when softened water is used only in small proportions as " make up." For this reason it may be preferred in certain cases to obtain all " make up " water by distillation instead of by water softener.

Excepting only abnormal waters as, for example, some pit and brackish waters and waters from streams, canals and the like adventitiously polluted by industrial effluent and sewage, most hard and corrosive waters can be softened by the lime-soda process in quite satisfactory manner for ordinary boiler installations, so as to prevent scale formation and corrosion. The direct losses due to scale in boilers and the like are frequently grossly exaggerated by vendors of softening apparatus and materials. The indirect

economies rising from the use of softened water—for example, continuity of running, saving of cleaning labour, and upkeep costs of boilers—are sufficient to justify water softening in most steam power installations where surface condensers are not used. The cost of water softening rarely exceeds one penny per 1,000 gallons, whereas a common price paid for towns' water is 1/6 per 1,000 gallons.

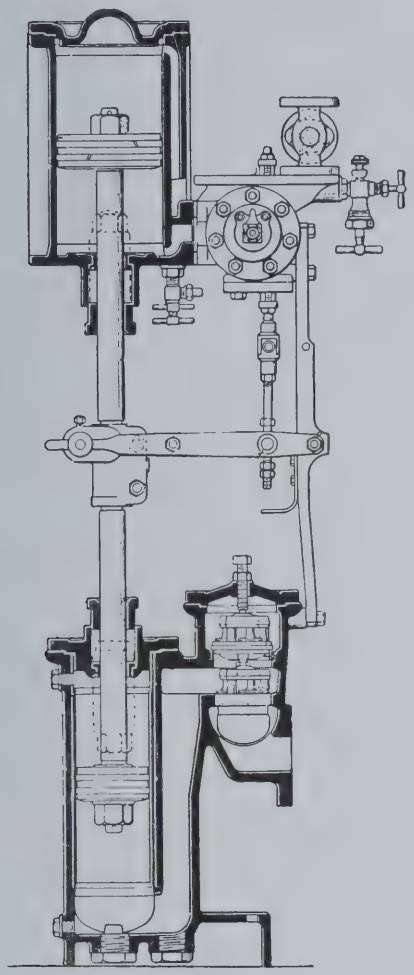


FIG. 6.

Treatment of Condensate for Grease. While there are available many designs of filter for extracting grease, of considerable value when no better means are possible, as for example in marine practice, complete extraction of emulsified oil from feed water by filtration alone is admittedly impossible, and it has been previously noted how serious may be the results following the admission of even traces of oil with the feed to modern high-pressure boilers.

Water softening as a means of grease elimination, in cases where the boiler feed water is drawn from the overflow of a jet condenser, is, if this water be fairly hard, a straightforward process. The scale-forming mineral matter released during the softening process seizes on to the microscopic grease globules with pronounced attraction. Generally, the grease particles render this combined suspended matter lighter than water and, if permitted, it will float upon the surface and can be blown off as a scum, obviating the necessity of final filtration. This is very desirable, as the contained grease, if put through a filtering medium, seriously increases the frequency of flushing and cleaning operations. Probably on account of first cost few water softeners are built to take advantage of this phenomenon.

When feed water is obtained from a surface condenser in greasy condition, following lubrication of reciprocating engines or auxiliaries, the only really effective method of extracting it is by putting it through an apparatus similar in principle to, but much smaller than a water softener, prior to filtration. In such apparatus an artificial precipitate is formed, generally by reaction between small doses of sulphate of alumina and sodium carbonate. Copperas and lime water are sometimes used alternatively. The mineral suspended matter thus produced has the same affinity for the emulsified grease as has been described above and the combined substances are amenable to very effective filtration through cages covered with filter cloth, flannel, Turkish towelling or the like.

ANALYSIS AND TREATMENT OF IMPURE WATERS.

Complete analysis of water is work for a specialist, but the writer has collected and summarised simple procedure for general and more-or-less unskilled employment which, if not strictly accurate and scientific, have been found practical and useful.

Apparatus and materials required:—1 pint Wanklyn standard soap solution; 1 pint N/50 standard acid; 1 pint N/50 standard sodium car-

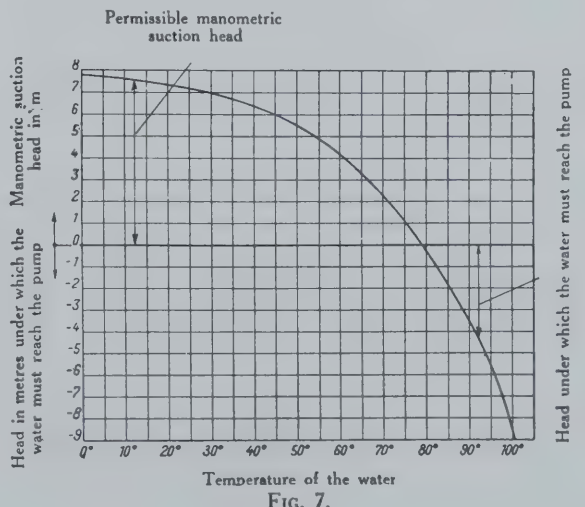


FIG. 7.

bonate; 1 pint silver nitrate Wanklyn strength; 2 oz. methyl orange; 2 oz. phenol phthalein; 2 oz. 10 per cent. neutral silver nitrate; 2 oz. potassium chromate; one 200 c.c. porcelain saucer; one 200 c.c. wide-mouthed stoppered bottle; four 25 c.c. burettes; one 250 c.c. graduated measure glass. All these may be obtained from many firms of manufacturing chemists at insignificant cost.

Total Hardness Test. Measure 70 c.c. of the hard water into the stoppered bottle and charge one burette with standard soap solution. Run the soap from the burette into the water, a few drops at a time, shaking the bottle violently after each addition. A lather will soon begin to form, which at first will quickly disappear, but after further soap additions and shaking will tend to persist. When this lather persists for three or four minutes, and on placing the open mouth of the bottle to the ear no "crackling" sound (due to bursting soap bubbles) can be heard, the hardness is neutralised. Read off the number of c.c. added from the burette, substract 1, and the result will be the total hardness (that is to say the number of grains per gallon of hardening salts calculated as if it all were calcium carbonate).

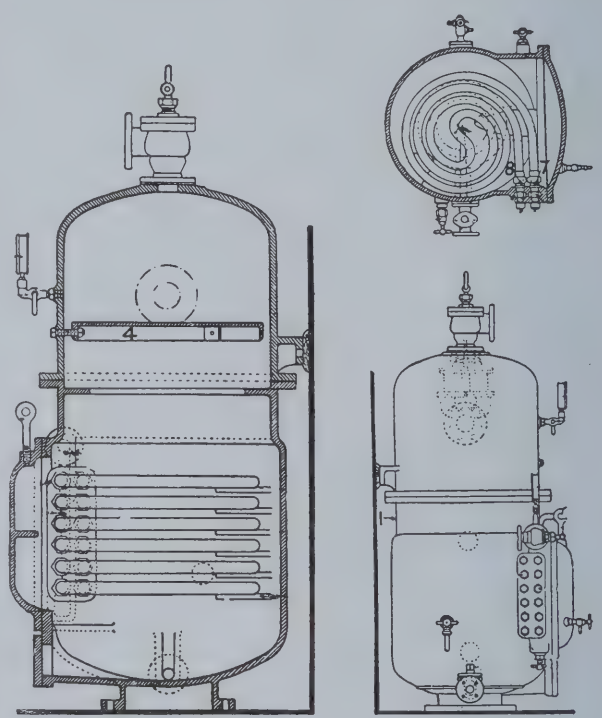


FIG. 8.

Two precautions are necessary in this test:—(1) If more than 16 c.c. of soap are required to obtain a persistent lather, make up a new sample of water, 35 c.c. of the hard water and 35 c.c. of distilled water and re-test, multiplying the final result (i.e., burette reading—1) by 2. (2) Having obtained and registered the above reading, add one or two more c.c. of soap. If the lather persists all is well. In some cases, however, with magnesium waters, the lather will disappear and the soap additions must be continuous until a second persistence is obtained.

Methyl Orange Alkalinity or Temporary Hardness Test. Measure out 70 c.c. of the hard water into the porcelain saucer and drop in one or two drops of methyl orange, which will produce a faint yellow colour. Charge a second burette with N/50 acid. Run the acid from the burette into the water, stirring all the time, until the yellow colour changes to pale pink. Read off the c.c. added to produce this change, which will be the temporary hardness.

Phenol-Phthalein Test. Proceed exactly as in the methyl orange test, substituting a few drops of phenol-phthalein in the 70 c.c. of hard water, and N/50 sodium carbonate in the third burette. If the water remains clear or milky white (i.e., acid) titrate with sodium carbonate until it changes to pink. The number of c.c. added will represent phenol-phthalein acidity. If, on the other hand, the water turns pink immediately on adding the phenol-phthalein it is alkaline. In this case titrate with N/50 acid as in the methyl orange test. The result will be the phenol-phthalein alkalinity.

Chlorides. Proceed exactly as with the previous two tests, using 70 c.c. of water and a drop of potassium chromate as indicator. Charge the fourth burette with Wanklyn-strength silver nitrate and titrate, until the pale yellow colour changes to pink. The burette reading will give the number of grains per gallon of chlorine as chlorides.

Experimental Softening. A simple and practical method of ascertaining the possible effects of lime-soda treatment on hard water and of the proportions of reagents required has been evolved by the writer for the use of attendants who are not trained chemists, and is here given. Advantageously, 280 c.c. of the raw water may be used. Upon the assumption that all the temporary hardness is due to calcium bi-carbonate and all the permanent hardness to calcium sulphate, the approximate treatment will be:—·8 lbs. of lime

(CaO) for each 10° of temporary hardness per 1,000 gallons; 1.12 of soda as Na_2CO_3 for each 10° of permanent hardness. The permanent hardness is of course the difference between the total hardness, as shown by the soap test, and the temporary hardness, as shown by the methyl-orange alkalinity test.

It is convenient to work with saturated lime water, which may be readily prepared by slacking a little burnt lime, placing in a large bottle, filling up with water, and after agitation leaving same standing until the whole of the undissolved lime precipitates, leaving clear lime water above. Then 16.4 c.c. of this clear lime water in 280 c.c. of the hard water is equivalent to .8 lbs. of lime per 1,000 gallons. Similarly it is convenient to add soda ash in solution form. Obtain from a chemist deci-normal $\left(\frac{N}{10}\right)$ sodium carbonate. 5.44 c.c. of this in 280 c.c. of water correspond with 1 lb. of soda ash per 1,000 gallons of hard water or :—$1.12 \times 5.44 = 6.09$ c.c. per 10° permanent hardness. Assume that we find:—By soap test, total hardness, 20°; by methyl orange test temporary hardness, 10°. Add these quantities, 16·4 c.c. lime water and 6.09 c.c. of $\left(\frac{N}{10}\right)$ sodium carbonate to 280 c.c. of the hard water in a 500 c.c. beaker. Stir well, warm over Bunsen burner (if necessary) to the temperature at which the water will be softened, and leave standing for two or three hours or until the released suspended matter has precipitated. Then test for total hardness and alkalinity as before.

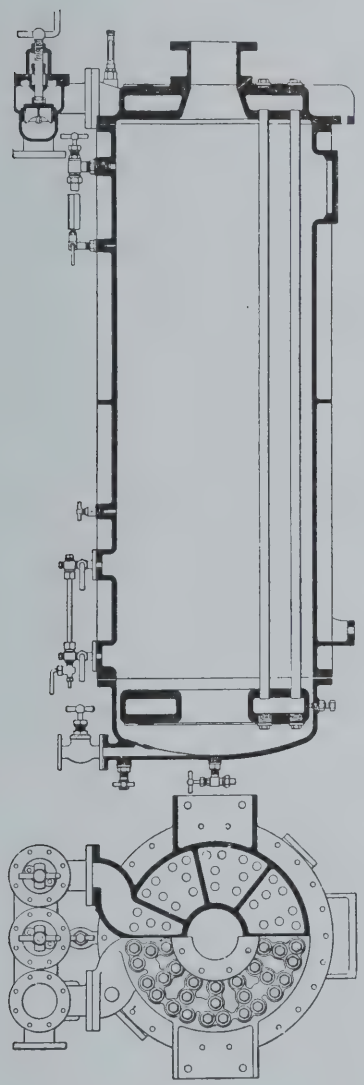


FIG. 9.

Most natural waters can be softened to between 3° and 5° total hardness without showing undue alkalinity. In good softening the methyl orange alkalinity will not exceed the total hardness by more than 1 point and the phenol phthalein alkalinity by more than .5°. Almost invariably it will be found that the above method fails to reduce the hardness to the degree named, and this is usually because insufficient lime water has been added. The amount given will only deal with the bi-carbonates in solution, whereas there is almost always free carbonic acid (CO_2) in a natural water calling for further addition of lime water.

It is an axiom in lime-soda softening that the hard water should receive as much lime as it will take without re-hardening, and this is readily tested qualitatively by silver nitrate solution. For example, when the treated sample has cleared, but before testing, pour two or three drops into a white saucer and add a little 10 per cent. silver nitrate solution. If the water remains clear or only throws down a white precipitate, the sample will stand more lime water. If, on the other hand, a dirty brown precipitate forms, too much lime water has been added. The correct addition of lime water is indicated by the merest suggestion of yellow colour in the saucer.

This brief " trial and error " method of arriving at the correct softening treatment for any hard water is perhaps somewhat unscientific, but is very useful in practice, well within the powers of an attendant untrained in chemistry and, after a little practice, much more rapid than more orthodox methods.

It may be deduced from the above notes that the most ready means of controlling a water softening plant is to work back from the softened effluent. One can readily judge by the aid of the three tests named—" total hardness " (by soap), " alkalinity " (by methyl-orange) and " excess lime " (by silver nitrate) —not only whether the water is adequately softened but, failing this, whether the lime and/or soda admixture is in excess or deficient, and can closely approximate the degree. Fig. 4 illustrates a lime-soda water softener designed by the writer to deal with 4,000 gallons of canal water per hour. Its distinctive

features are the separate reaction tank, the large sedimentation capacity and double filtration, primarily upward through filter cloths followed by downward filtration through sharp sand. Fig. 5 represents the automatic chemical feed gear.

It may be permissible, as an illustration of the value of water softening in certain cases to refer to the record of this plant. It serves four 30ft. by 8½ft. Lancashire boilers which work 24 hours per day, with average evaporation of 12,500 lbs. each boiler per hour. Prior to the installation a boiler was laid off every fortnight for cleaning and the economisers were virtually useless, due to scale. Now the boilers are run for three months between openings which are merely for inspection, and the economiser is clean.

THE "BASE EXCHANGE" SYSTEM OF WATER SOFTENING.

This system, of comparatively recent discovery, involves passing the hard water through a bed of granular material containing soda, alumina, and silica. Such material is found in natural deposits, described as "zeolites," but is also now manufactured by different firms and processes. The general action is much the same with all of them, but special claims of efficiency are made for those most recently introduced.

The term "base-exchange" correctly expresses what occurs during the process. There is no reaction leading to the conversion of soluble into insoluble matter and followed by precipitation of the latter as in ordinary water softening. Assume a water, hard through bi-carbonate of calcium in solution, passed through a "base exchange" filter bed. The calcium and sodium elements are exchanged, bi-carbonate of soda, a non-hardening salt, remaining in the water and calcium taking its place in the filtering medium. This can only go on until all or most of the original sodium has been replaced in the bed by calcium. The bed then becomes inert, but if temporarily isolated and "drowned" in strong solution of

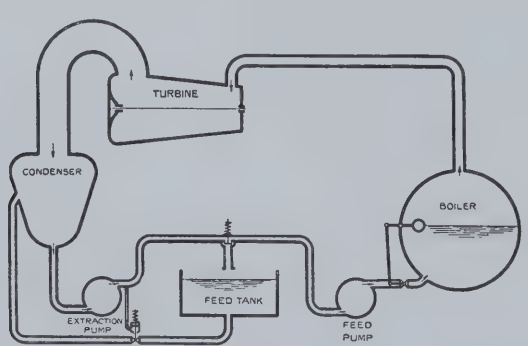


Fig. 10.

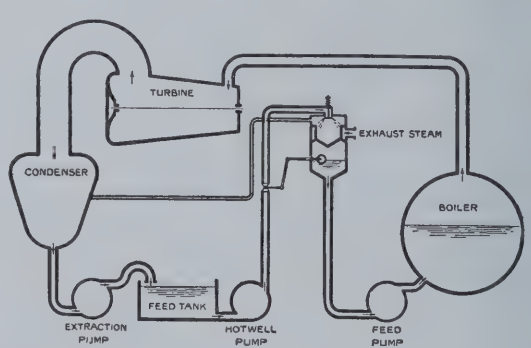


Fig. 11.

chloride of sodium, the sodium and calcium again replace one another, the bed reverts to its original condition and the resultant chloride of calcium is run to waste.

The exchanges in regard to the hardening salts, sulphate of calcium and carbonates and sulphates of magnesium, are of exactly the same nature; in each case the sodium salts exchange for calcium and magnesium salts in the water, and so the process goes on indefinitely.

Properly installed, this system is capable of reducing any water to zero hardness. As regards "temporary" hardness the system is not so good as ordinary softening by lime in that, while the latter removes the cause (bi-carbonates of calcium or magnesium) and leaves nothing behind, the base-exchange system only replaces these with sodium salts which may be objectionable in steam raising. It is not, therefore, uncommon to combine the systems of normal and "base-exchange" softening, using the former, as the cheaper and most satisfactory method, to reduce considerably the temporary hardness, and removing (or replacing) the residual temporary and all the permanent hardness by the "base exchange" method.

It is difficult, having in view the varieties of "base exchange" material offered, to give useful figures for its employment, but the following notes may be useful as conveying a general idea:—

(*a*) The filter bed should be advantageously about 6ft. deep, this giving suitable contact period without setting up undue resistance.

(*b*) The water should be absolutely free from suspended matter or the filtrant will deteriorate.

(*c*) A moderately hard water (say 10°) will call for about 12 cub. ft. capacity of filter per 1,000 gallons of water per hour, which will be effective for ten hours between regenerations.

(*d*) The amount of salt required will be about 3 lbs. per 1,000 gallons of water softened.

The opinion is fairly generally held that, in view of the limitations mentioned and cost of regeneration, the "base exchange" system of water softening is less suitable for power-house purposes than the older lime-soda process; but, on the other hand, it has a wide field of utility for industrial and domestic purposes.

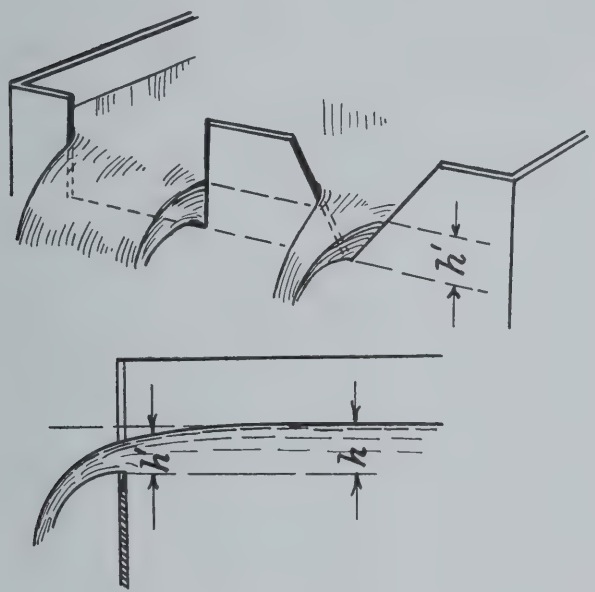


Fig. 12.

Feed Pumps.

Boiler feeding pumps of the "crank-shaft" type, such as the once popular "Cameron" steam pump and even the "three-throw" electrically-driven type are now rarely installed. For marine service and comparatively small land work the "duplex" direct-acting type of steam pump is largely used, but has, in popular favour, been superseded by the straight line directing type introduced by and commonly described as "Weir." This type is, however, manufactured, with comparatively slight detail modification, by several prominent British firms, and with a degree of perfection that would make comparisons invidious. This type of pump, double acting and fitted to run at low piston speed, leaves little to be desired. The flow is remarkably steady and, upon the writer's personal tests, the displacement efficiency generally exceeds 95 per cent. As a rule the water end, piston, valves, and seatings, are made of or lined with phosphor bronze, so as to be immune from corrosive action of the water. The steam consumption seems to average about 60 lbs. per pump H.P., but this as a rule is of little consequence, since the exhaust can be, and generally is, used for preheating the feed water.

So perfect are these pumps as regards regular displacement when running at low speeds, and when carefully maintained, that, if fitted with stroke counters or suitable recording devices, they may be regarded as water meters quite as accurate (under pressure conditions) as many types of apparatus offered for metering only (Fig. 6).

Latterly, for boiler feeding upon anything approaching a large scale (say 2,000 gallons or upwards per hour) the centrifugal high duty pump has displaced all others in popular favour. Such pumps, multiple stage, are capable of feeding boilers working up to any modern pressure (500 lbs. per sq. in. for example) and possess many obvious advantages. For example, they occupy very little space and can be coupled, for direct drive, either to the spindle of a small independent steam turbine or an electric motor, without any intermediate gear. They are distinctly more fool-proof in that, if the discharge passage be closed, no excessive pressure such as would burst the pipes is set up; the impellor continues to rotate, merely churning the contained water, absorbing comparatively little power. As a rule, a centrifugal feed pump is designed to discharge at a maximum pressure exceeding the normal boiler pressure by about 150 lbs. per sq. in., and in no circumstances can this margin be exceeded. Thus they are excellently adapted to work with boilers provided with automatic feed control valves, without any intermediate compensating or relief gear. Turbo-driven feed pumps are now usually fitted with hydraulic governors whereby a constant *difference* of pressure is always automatically maintained between pump discharge and boiler steam; that is to say when the feed valves are closed wholly or partially the turbine speed is automatically reduced in proportion.

The relative claims of the direct-coupled steam turbine and electric motor for driving centrifugal feed pumps (or for that matter any centrifugal pumps used in the power house) are dependent upon local conditions. Broadly, if there be use for the exhaust of the turbine, it is the more economical proposition, in that, by the " pass out " system, power equivalent to the electrical unit is frequently obtained at a net steam expenditure not exceeding 5 lbs., or less than half the steam expenditure of the unit drawn from the switchboard. It is common practice in large power stations to duplicate the feed pump service, installing both turbo-driven and motor-driven sets. It is significant, within the writer's observations, that in general service the motor-driven pumps are more commonly in use, the turbo sets standing in reserve.

The question of location in a power house of centrifugal feed pumps is one of considerable importance in that, having to pump hot water, there is a limit to their suctional effect. The graph (Fig. 7), taken from a brochure published by Messrs. Sulzer Bros., illustrates this point.

Feed-water heaters and evaporators.

Reference has been made previously, in regard to the call for absolutely pure make-up feed water for modern high-pressure boilers, to the frequent substitution of distilling plant for water softening plant. The same class of apparatus is frequently used for heating feed water up to boiler temperature by live steam leaving the boiler only to add the latent heat necessary for the change of state. In such cases the feed heater becomes virtually part of the boiler, and is the means of relieving the latter of sundry stresses and strains rising from temperature differences. The efficiency of such apparatus is so high that, with due precautions, the radiation losses are practically negligible. Feed-water heaters working at modern pressures and temperatures would, unless very carefully designed to allow of the necessary flexibility, give endless trouble. For example, straight tubes expanded into rigid tube plates, with steam inside and water outside, or the converse, would be quite unsuitable. The most common design is the marine evaporator or distiller type in which steam is put through tortuous copper coils in the lower part of a cylindrical chamber through which the water is pumped. The tube surface being spiral, or of equivalent contour, is free to expand or contract under temperature variations without springing the connections. Generally a large door is provided in the lower portion of the chamber through which deposits upon the exterior of the tubes may be readily removed (Fig. 8).

Another type may be compared in general outline to a vertical surface condenser having straight tubes, but, while the upper plate is rigid within the casing, the lower " header " is in the form of a floating box, and the headers are divided into an even number of compartments with flow down one and up the next. In this form it is usual to put water through the tubes with steam outside, screwed plugs being provided opposite each tube for cleaning; the exchange of heat is effected in small space and with low maintenance charges (Fig. 9).

Reference has been made, in connection with high-pressure boilers and particularly water-tube boilers, to the deleterious effects of air, dissolved or free, in feed water. As with modern steam turbine plant the feed water, or upwards of 90 per cent. of it, is derived from condensate, the problem of providing air-free water has involved the exercise of considerable ingenuity in recent power station design. It is usual, whatever type of water-extraction pump be used (i.e., reciprocating or rotary) to extract the last traces of air from the condenser, frequently by steam ejector; but the difficulty is to prevent re-solution between the extraction pump and the feed pump. At first glance it might appear easy by the simple means of coupling the suction branch of the feed pump to the discharge branch of the extraction pump in closed conduit, but it is immediately obvious on consideration that, to keep the balance between the two and to introduce meanwhile the required " make-up " water to compensate for inevitable losses is impossible. The simple interposition of an open feed tank of considerable capacity between the two pumps will not do, as it provides opportunity for the water to take up air. Closed feed tanks have been tried, with slight steam introduction above the water to prevent air ingress, but this is found to interfere with satisfactory and regular suctional effect of the feed pumps. The employment of a high-level feed balancing tank with discharge from its base into the feed pump suction, and with automatic water-regulating valve on the feed pump discharge, is now very common and, without being perfect, is generally effective; but a still

better arrangement devised by Messrs. G. & J. Weir, Ltd., is shown diagrammatically in Fig. 10. The effect of this may be described as follows:—

If the feed pump is supplying more water than the boilers require, as determined by the automatic water-level valve, the surplus escapes into the feed tank. If there is shortage of water to maintain the boiler level an automatic valve, pressure controlled from the connecting pipe, permits make-up water to flow from the feed tank, not directly to the feed pump but *via* the condenser, where it is immediately de-aerated and comes into the circuit.

Still another and perhaps simpler method is commonly used in smaller plants, but this involves an extra pump in the circuit. The extraction pump discharges into an open balancing tank from which the additional pump delivers it, in its condition of aeration, in fine sprays to a chamber in which it is preheated by direct contact with steam, live or exhaust, whereby the air is freed. The hot water level, regulated by float control valve operating upon water inlet pipe, is controlled to provide constant head over the feed pump suction, while the air released is conducted from the top of the vessel by a small pipe back to the main condenser, where it is at once extracted and discharged. This very efficient arrangement, adopted by several well-known firms, is diagrammatically illustrated in Fig. 11.

Feed-water heating is to-day regarded in rather a different manner to the fashion of twenty years ago. Engineers then regarded their boiler plant as the means of raising water from or near atmospheric or hot-well temperature to steam at the required pressure, except in cases where there was exhaust steam, otherwise useless, available for preheating. The use of live steam for feed heating was deprecated, except in some cases in marine practice, as necessarily involving radiation losses. To-day, under high temperature and pressure conditions, it is found advantageous to raise the feed water to, or almost to, steam temperature before its introduction to boiler or economiser, even by the utilisation of high-pressure steam for the purpose, that is to say to leave to the boiler only the duty of adding the latent heat. Thermal exchange of this nature involves almost inappreciable loss by radiation in a well-devised plant, and such equalisation of temperatures through the boiler is a safeguard against undue straining and leakage. One of the most interesting features in modern power-house design is the free adoption of the "bleeding" or "pass out" system for providing heating steam. This chapter is hardly the place for detailed analysis of this system, but a very short perspective view of its possibilities may not be inopportune. It calls for very careful balancing both in design and operation of the plant. Assume a centrifugal feed pump to deliver 50,000 lbs. of water per hour to a boiler working at 250 lbs. pressure which will absorb about 20 kw. per hour. If it be electrically driven, taking it that the electrical unit costs 15 lbs. in steam, the steam consumption will be 300 lbs. per hour. If, on the other hand, the pump be directly driven by a H.P. steam turbine it will call for 20×60=say 1,200 lbs. of steam per hour, the greater part of which will appear as exhaust at, say, 10 lbs. pressure, available for feed heating. This exhaust, transferred to the feed water, will raise its temperature about 23.2° F., or in other words the live steam will effect the pumping, giving a surplus of about 1,160,400 B.Th.U. This 1,160,400 B.Th.U. corresponds approximately to 965 lbs. of live steam at 250 lbs. pressure; so that by the electrical pump our feeding has involved the expenditure of 300 lbs. of steam; and by the turbo pump we have expended *net* for pumping 1,200-965, only 235 lbs. of steam. This example, taken quite at random, shows that from the thermal standpoint, there would be not much to choose between the two methods on the assumed basis, but it demonstrates the room for careful analysis in deciding whether auxiliaries should be steam or electrically driven.

The importance of purity of boiler feed water in the modern high-pressure power house has inspired much ingenuity in devising indicators for the detection of any deleterious leakage thereto. Of these the Weir corrosion detector is perhaps the most obvious and direct in its action. Its essential feature is a small disc of highly polished and burnished steel mounted in a small gun-metal fitting with a plate glass window in front and small valved inlet behind for hot steam. A small stream of the feed water is allowed to flow past and in contact with the burnished surface, which is kept hot by the steam behind. If the water be pure and non-corrosive, no change upon the surface of the disc appears. If on the other hand there be dissolved oxygen or other corrosive element in the water the disc becomes tarnished in a few minutes.

A much more delicate and elaborate instrument is the "Dionic" water tester. This is dependent upon varying electrical conductivities of water in the pure state and with matter in solution and is said to be so delicate that it will distinguish between commercial samples of distilled water or will detect the presence of salts in solution when chemical tests have failed.

The apparatus is made either portable or for permanent attachment in a feed system. Varying resistance is indicated by a delicate ohm meter which can be coupled to continuous recording apparatus.

Water metering.

One need not emphasise here the importance of the thermometry and metering of water in the power house in relation to keeping heat-balance accounts and the detection of thermal leakage.

Little need be said in regard to thermometry other than reference to progress during recent years in the development of the "recording" and "distance" thermometer. By means of such instruments the responsible head of a power station is enabled not only to ascertain and check readings personally, but also to see at a glance when there is any departure from the normal.

The metering of large volumes of water *not* under pressure is a simple matter, and the weir type of meter has come to be regarded as the standard apparatus. It depends upon the principle that the volume of water flowing over a weir of given shape and size and at constant head will be constant. The forms of weir usually employed are the "rectangular" and the "90° V notch" as illustrated in Fig. 12.

The volumes of water passing over these weirs are given by the following well-known formulae:—

For 90° V notch. $Q=1{,}174\ h^{2.48}$

For rectangular weir. $Q=1{,}500\left(1-\frac{h}{5}\right)h^{\frac{3}{2}}$

When Q=lbs. of water per hour.

h =head in inches.

l =length in inches of rectangular weir.

(NOTE.—On Fig. 12 the head immediately over the weir is shown as (h^1). The true head (h) must be measured some distance back from the weir.)

Many types of water meter for working under pressure are offered, some dependent upon purely mechanical operation, for example by the stream of water in a pipe passing and rotating a turbine wheel or propellor. Others, also mechanical, and strictly of the displacement type, may be regarded as hydraulic engines, reciprocating or rotary, in which the water, in flowing through, operates a piston or diaphragm whose vibrations are recorded. These types appear to do good and reliable work in municipal and like service, when operating with cold water and under reasonably steady flow. The writer after many years' experience, has lost faith in them, when working under power-house conditions of varying temperature and spasmodic flow. There is among engineers a natural leaning towards the "positive" as compared with the "inferential," but, in water metering (and also in the metering of gases) under pressure, "inferential" systems have, in the writer's experience, proved the more reliable. That he is not alone in this opinion is to some extent proved by the fact that most constructors of power-house plant, and most consulting engineers responsible for its installation, are content to base official trials upon the records and readings of meters which can only be so regarded. The general principle involved is that of measuring the drop in pressure resulting from an obstruction placed in, or reduction of thoroughfare through, the conduit pipe.

One finds the apparatus in its most perfect form in the well-known Venturi meter in which the pipe conveying the water to be measured is reduced and then increased cone-wise, the static heads being taken at the large and smallest diameters. Almost equally reliable results are obtained, with slightly increased loss of head, by the mere insertion between the flanges of the conduit pipe of a thin metallic diaphragm with central circular hole cut in, the pressure differences being registered immediately before and after the diaphragm.

This type of apparatus has been developed with the greatest care and is capable of registering, when suitably applied, with a margin of inaccuracy not exceeding 1 per cent. between wide limits of flow. Direct readings or records can be taken at considerable distances from the apparatus, or by electrical transmission, at unlimited distances.

Chapter 6.

FUEL ECONOMY AND STEAM RAISING IN SHIPS.

By J. W. R. Williamson, M.I.N.A.

Viewed broadly, economy of fuel in producing power to drive a ship should be on an exactly similar basis as fuel economy in producing power on land. A certain amount of thermal units is purchased in the form of coal or oil, and this fuel is transmuted into power units either directly as in an internal combustion engine, or by means of a steam medium, as in the reciprocating engine or turbine. The same principles govern the economical outcome of this operation at sea as on land, but the parallel ends here, and there are several important features of difference which make the highest fuel economy which is possible in a land power station, difficult to attain in a marine installation.

The land power station produces power for a well-defined area, whose requirements can be easily estimated from carefully compiled data, and suitable additions can be allowed for in the original layout to meet the growing demand. It is in a fixed position, is designed for extensions, and within certain limits which have not yet been reached, the larger the power units the better the economy all to the advantage of the land station.

The marine power installation has different conditions to meet. The primary difference is that it is a moving power station, and as it has to move itself limitations of space and weight and considerations of shape are of the utmost importance. These are serious drawbacks when the highest fuel economy has to be considered. Further, the marine installation has also to carry its fuel supply with it, and it is in direct and active competition with numerous other installations to secure a financial return on its capital expenditure and cost of operation. It has to depend for its return on freights settled by this competition which can only be raised when improved trade admits of the increase. Owing to the limits imposed by these factors the money required for the most economical marine installation is often not available, and the shipowner has to be content with the best he can afford.

The marine engineer, however, is gradually improving his sea power plants where possible on the lines of recent land power practice, and when the shipowner is satisfied that these improvements are worthy and reliable they will, undoubtedly, be generally adopted. Reliability is the most important feature which the shipowner has to consider, and very often economy is sacrificed to ensure reliability, because a breakdown in a moving power station in a distant port involves very serious losses, and one lost voyage probably means no profit on that particular vessel for the year. Here, again, the land power station is safeguarded, because invariably provision is made for a standby plant, which is profitable to a community but which cannot be provided in an individual vessel. Moreover, reliability is not merely a feature of the machine, but is also a feature of the personnel, and stormy weather imposes a severe strain on marine engineers, which the engineers in the land power station hardly ever experience except where they serve large overhead networks in countries liable to violent thunder storms, as in India and South Africa.

Personnel.

The training of the personnel who are to operate the marine installation is a most important feature of fuel economy, but, unfortunately, considerations of fuel economy are only just beginning to occupy a place in the marine engineer's training, and even to-day to many of the older sea-going engineers the coal economy problem is only appreciated as an alternative between forced and natural draught conditions.

The sea-going engineer is said to be conservative, but it is not merely his conservatism which produces lack of progressiveness; it is largely due to the stereotyped conditions of his training, and the marine engineer is the victim of circumstances.

The whole of his training and advancement are governed by the Board of Trade examinations, which the marine engineer has to pass to obtain his chief engineer's certificate. The questions asked at these examinations from year to year can scarcely be termed progressive as regards economical considerations: they are based entirely on proving the reliability of the individual, and rightly so. The trouble is that, unfortunately, the average engineer and his employer consider that these examinations constitute the only training necessary. Fuel economy is not considered as part of the training at all, and the marine engineer has to pick this information up as best he can. Many have very few facilities for acquiring this knowledge. A shipowner who desires his engineering personnel to pay particular attention to economy would do well to issue, through his superintendent engineer, some carefully worded instructions regarding fuel economy, and institute a system of bonuses to be paid to all the engineers for fuel saved, making due allowances for adverse weather and other disturbing factors. This would, undoubtedly, provide an incentive and a freshening of interest on the part of the staff, and it would further their knowledge of fuel economy to the owner's ultimate benefit.

The conservatism of marine engineers is fostered by a further cause. When a shipowner decides to come into the market for new tonnage, it is the usual practice to leave the question of the machinery part of the specification entirely in the hands of the superintending engineer. Usually, superintendent engineers are appointed from the ranks of the chief engineers who are operating in the owners' fleet. It is a very debatable point whether such a superintendent is not biased too much by the experience of his earlier years when guiding his owners on the large questions involved in adopting new machinery types. He, naturally, desires to repeat the type or types which he knows intimately, partly to avoid trouble and partly on account of his long experience with the engines he knows. Shipowners who desire to augment their fleet and make progressive improvements would be well advised from time to time to obtain expert advice from one or more consulting marine engineers or naval architects, whose particular business it is to watch each new advance that is made, weigh up its possibilities in all its phases and give their unbiased verdict on the best type of machinery for the particular service of the owners. It is not humanly possible for a busy superintendent engineer to advise on these large questions when he has a fleet of steamers to occupy his close attention. The argument turns on a separation of functions. Again, when improved types are adopted, they should be adopted thoroughly. The engineers who are to handle the new type should be trained in the operation of a similar type for a lengthy period before proceeding to sea in charge. This may appear difficult to arrange, but the superintendent who knows his business will find means to accomplish it, because such a procedure nearly always means success, just as lack of this precaution risks failure.

PRESENT PRACTICE IN STEAM RAISING.

Coal Fuel.

In spite of the numerous new types of machinery in vogue, the majority of the steam engines are still supplied with steam from the single or double-ended cylindrical multitubular boiler, fitted with two, three or four furnaces, fired by hand, with coal fuel, under forced or natural draught conditions. This type of boiler has been in vogue for over fifty years, and improvements have been very slow. There have been increases in boiler pressures, but very few cylindrical marine boilers have been built to withstand a higher pressure than 225 lbs. per square inch, owing to the very great thickness of the shell plating required, and, even to-day, the majority of these boilers rarely work at a pressure beyond 200 lbs. per square inch.

The one outstanding improvement made in connection with the marine boiler was the introduction of forced draught, combined with the adoption of air heating by means of the funnel gases, introduced by Mr. James Howden, of Glasgow. Forced draught alone was scarcely an economical improvement apart from the fact that it enabled smaller boilers to be used to produce sufficient steam for the same powers, when compared with boilers under natural draught conditions, but the heating of the furnace air was a real step towards economy, since it is a regenerative device. That the heating of the furnace air was not appreciated in its true light is proved by the considerable lapse of time that ensued, before it was realised that greatly

improved boiler efficiencies could be obtained by extracting considerably more heat from the funnel gases by this method. In fact, it is only the intensity of competition, and the urgent need for fuel economy in all directions which has emphasised the importance of this.

The use of superheated steam during the last twenty years may be mentioned as an improvement in economy, but this economy is obtained because of the great reduction in condensation which occurs, when superheated steam is expanded in the engines as compared with saturated steam, and is, actually, a gain at the engine and not in the boiler. In fact, as regards the marine cylindrical boiler, this is not the ideal steam generator to which to apply a group of elements for superheating the steam. Either the superheater elements have to be arranged inside the boiler tubes, in which case there is, undoubtedly, a falling off in the evaporative performance of the boiler, or, the superheater elements are arranged entirely in the top of the smoke-box, in which case the sooting up of the elements is a severe handicap, and the degree of superheat is decidedly limited. Nevertheless, the overall economy of the whole plant is improved by the adoption of superheated steam.

Furnace and fuel.

The one feature of the marine boiler which so far has remained unimproved, is the method employed for burning the coal, and here there are glaring inefficiencies. The real problem of economy in steam raising with coal fuel is the efficient mixing of the correct proportions of fuel and oxygen from the air to enable complete and rapid combustion to take place with as little cooling effect as possible. Nothing approaching this ideal condition takes place on board ship. Ordinary coal fuel, as it is delivered into the bunkers of a vessel, is of all shapes and sizes, from "smalls" to very large lumps. It is true that the large lumps are broken down, but this has to be done by hand, and by the stokers who have also to shovel the coal into the furnace and slice and rake the burning fuel. Therefore, it usually happens that quite large lumps find their way into the furnaces. The marine firegrate is badly designed; the air spaces are not frequent enough, and are usually too wide, thus preventing good combustion, even of the lower layers of coal. But, however efficient the grate, hand-firing has its limitations. Forced draught makes it imperative to have a grate completely covered, and, naturally, it becomes too well covered, and the fires are too thick. In addition, the frequent necessity of opening the fire doors to renew the fires, to rake and slice, all involve loss of heat. With a well-designed firegrate, it is possible that the lower layers of coal directly in contact with the air below the grate are efficiently burned, but the air is then contaminated with the burnt gases, and the superimposed layers of coal are not effectively burned. Hence, it is necessary to introduce an air supply over the top of the fires to assist in the combustion of the upper layers of coal, and the wastage of heat is excessive. It very seldom happens that the CO_2 percentage in the funnel gases of a marine cylindrical boiler fired with coal exceeds 10 per cent., and this represents about 80 per cent. excess air with a considerable cooling effect. It is hardly to be wondered at that the efficiency of such a boiler on service seldom reaches 70 per cent. Inefficient combustion has the further effect of causing a large soot deposit in the boiler tubes which reduces their heat transmission value, and, of course, involves continuous attention for cleaning. Hand firing is the bugbear of the coal-fired marine boiler, whichever type is used, and until some improved method is introduced for handling the coal mechanically from bunkers to furnaces, the efficiency of the coal-fired installation will remain low, and there will be wastage of fuel. From a national point of view, coal is the fuel which should be used in British-owned vessels, and the coal-fired cylindrical marine boiler is out of date as an efficient steam raiser. Owners who are contemplating new steam tonnage with coal fuel would do well to consider the alternative and more efficient units.

Oil Fuel.

Oil fuel for steam raising must be considered briefly, but it has not the same importance for the nation as coal fuel, as oil found in this country is insignificant in quantity. It has, however, certain outstanding advantages. Since it is in liquid form, it can be very easily pumped on board ship, and carried in otherwise unoccupied spaces, where coal could not be carried. It can be handled mechanically in the ship by means of pumps and fed directly to the furnaces so that personnel is reduced; firing is more efficient

and there is no unnecessary cooling of the fires when firing, as is the case with handled coal. It is, therefore, largely employed in steam-driven passenger vessels, as fuelling can be carried out rapidly and in a cleanly manner.

The main objection to the use of oil fuel is its high cost, especially in this country, since all the oil has to be shipped here from foreign oil fields. In passing, it may be pointed out that shipowners know the value of having their boilers equipped for burning either coal or oil where such arrangements are feasible, since it enables them to make better oil fuel contracts.

A higher efficiency can be obtained from the cylindrical boiler which is fired with oil fuel instead of coal, provided the units are carefully selected. One of the most necessary features is an efficient oil fuel heater which is now obtainable.

The essentials of efficient oil fuel burning are a short, well-spread flame to take advantage of the whole of the heating surface and to lock the air supply (except where special conditions require a long flame), fine atomisation of the oil, efficient heating of the oil fuel and air supply, steadiness of oil pressure and air pressure, and complete mixing of heated oil and heated air in the correct proportions. Efficiency of combustion can be determined by the CO_2 percentage in the funnel exhaust gases, and the temperature of these gases, 13 per cent. to 14 per cent. for the former, and 400° F. for the latter, being considered good combustion. The efficiency of a cylindrical marine boiler with oil firing may reach 75 per cent. on service, but as still higher efficiencies can be obtained from water-tube oil-fired boilers, the return-tube cylindrical boiler for marine installations will be gradually eliminated.

The Water-tube Boiler.

The water-tube boiler has, for long, been used in land power stations in some form. In fact, no modern land station uses any other type, because of its higher efficiency. It has, however, made very slow progress in mercantile marine installations, largely because of the fear of priming, resulting from salt water getting into the boiler through leaky condenser tubes. The condenser tube problem, however, is in a fair way to being solved, either by the use of cupro-nickel or Monel metal condenser tubes, and there is no doubt that the coming years will see a very large increase in the use of water-tube boilers for marine installations. Besides its greater efficiency, it has the advantage of being capable of raising steam rapidly, responds easily to change of steam generation, shows a great saving in weight, and can be easily forced. On the other hand, it is very susceptible to indifferent stoking, and fouls rapidly unless every precaution is taken with the feed supply.

With coal fuel, however, a water-tube boiler can be fired by hand and maintain a high efficiency, provided special precautions are taken to keep the firebars well covered, and firing is regular and well done. This is shown by the efficiency of 79 per cent. attained with the hand-fired boilers of the " King George V.," as recorded during the official trials.

As has been found in land stations, however, mechanical stokers afford a means of more efficient firing of coal fuel and save labour, and there is little doubt that some form of mechanical stoker will become a feature of marine installations fitted with coal-fired water-tube boilers, when still higher efficiencies will be obtained. The main reasons for higher efficiencies being reached with water-tube boilers are a much improved circulation of the water, and, consequently, a more rapid absorption of the heat in the furnace gases, as well as the improvement which can be effected in the disposition of the heating elements. The evaporative, superheating, air heating and feed heating elements can be arranged so as to obtain the maximum effective results, each without interference from the others, whereas, with a cylindrical boiler, the disposition of these elements is of necessity a compromise. Further, the large combustion chamber ensures that even with the disadvantage of burning somewhat thick layers of coal on a fire grate, the resultant unburnt gases rising from the fires are much more completely burnt than is possible in a marine cylindrical boiler.

The oil-fired water-tube boiler, as might be expected, produces an even higher efficiency than the similar coal-fired boiler, retaining all the advantages claimed for this system with cylindrical boilers.

Coal economy can, therefore, in some measure, be attained by adopting water-tube boilers, but with mechanical stokers a limited size of coal is required, which has to be carefully screened, either before bunkering, or on board before firing, and this can only be obtained at a price, or by the extra complication of mechanical crushing. Economical considerations, therefore, lead to the question of the possibility of still further reducing fuel costs by avoiding these disabilities.

Pulverised coal for marine installations.

The question of using pulverised coal for ships' boilers must be faced in the near future. Pulverised coal has been in use for land power stations for some considerable time, and is now well past the experimental stage. It has practically all the advantages already claimed for oil fuel, and a further advantage is that the cost of coal suitable for pulverising would be less than the present cost of navigation coal. The use of pulverised coal, so far, has been entirely restricted to water-tube boilers, the marine cylindrical boiler presenting many difficulties to the successful application of this method of firing.

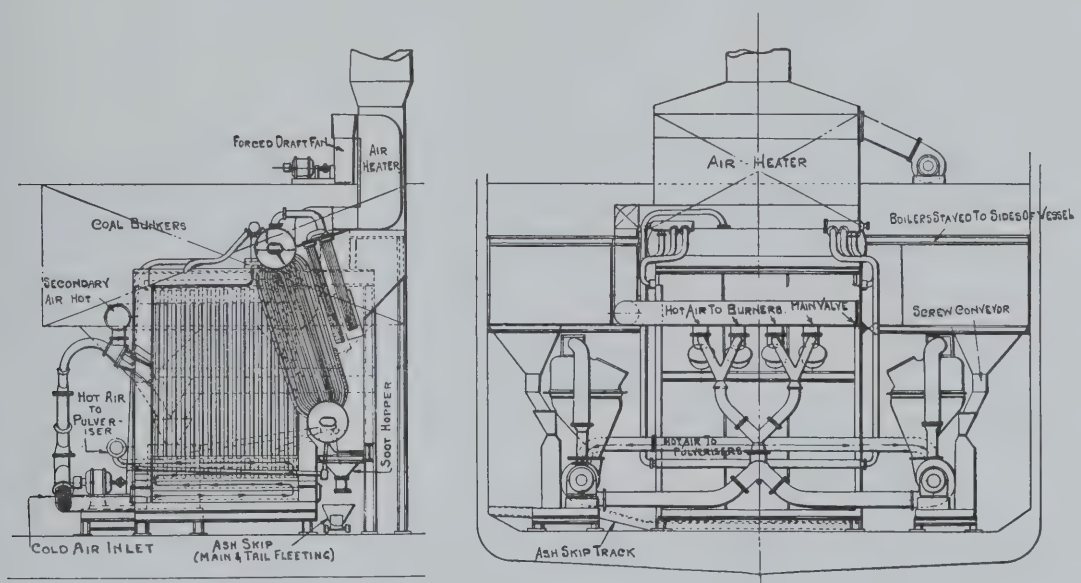


FIG. 1.—*Woodeson W.T. Boiler equipped for Pulverised Fuel Firing.*

For marine purposes, experiments are being carried out in America, but no authentic results have as yet been published. Keeping in mind the necessity of having as simple an installation as possible for use on board ship, it is, nevertheless, considered inadvisable to carry pulverised fuel in ships' bunkers initially, but lower grade coal would be bunkered on board, as at present, and pulverised as required.

There would, however, be many additional advantages to be gained if the coal fuel was pulverised on shore and loaded into ships' bunkers as powdered fuel. Coaling ship under these conditions would be as cleanly and rapid as is now possible with oil fuel, the degree of pulverisation could be determined during loading, and the price paid for the fuel would be based on this grading and the calorific value.

There is, however, the disadvantage of loading such finely pulverised coal into ships' bunkers unless the air in the bunkers is first displaced by an inert gas, owing to the danger of explosion by spontaneous combustion when such finely divided coal is mixed with the air in the bunkers.

The pulverisation of coal, however, can be safely carried out on board ship by unit pulverisers, as the quantity of fuel pulverised at one time is always small, and is not intimately mixed with sufficient air for combustion until it reaches the burners.

For the effective introduction of pulverised coal for marine purposes, small low-grade coal would be bunkered, and pulverisation would be carried out on board by unit pulverisers. Provided the system

from bunker to burners is reasonably air-tight, and care is taken to avoid leaks, such a method would be quite safe from spontaneous combustion.

As the result of long experiment, Messrs. Clarke, Chapman & Co. have devised a burner with which combustion is completed seven feet from the burner, and this feature makes this type of burner particularly adaptable to marine boilers, owing to the limited space available in ships' stokeholds. This burner, in operation with a " Woodeson " water-tube boiler, is shown in Fig. 1. The bunkers have been shown, for convenience, above the pulveriser hoppers, but they could be arranged lower down and athwartships.

The low cost of the fuel is particularly attractive to the shipowner. Quotations have been obtained for the coal per ton of " washed gum " and " washed gum " mixed with " pearls " from the Scottish coal-

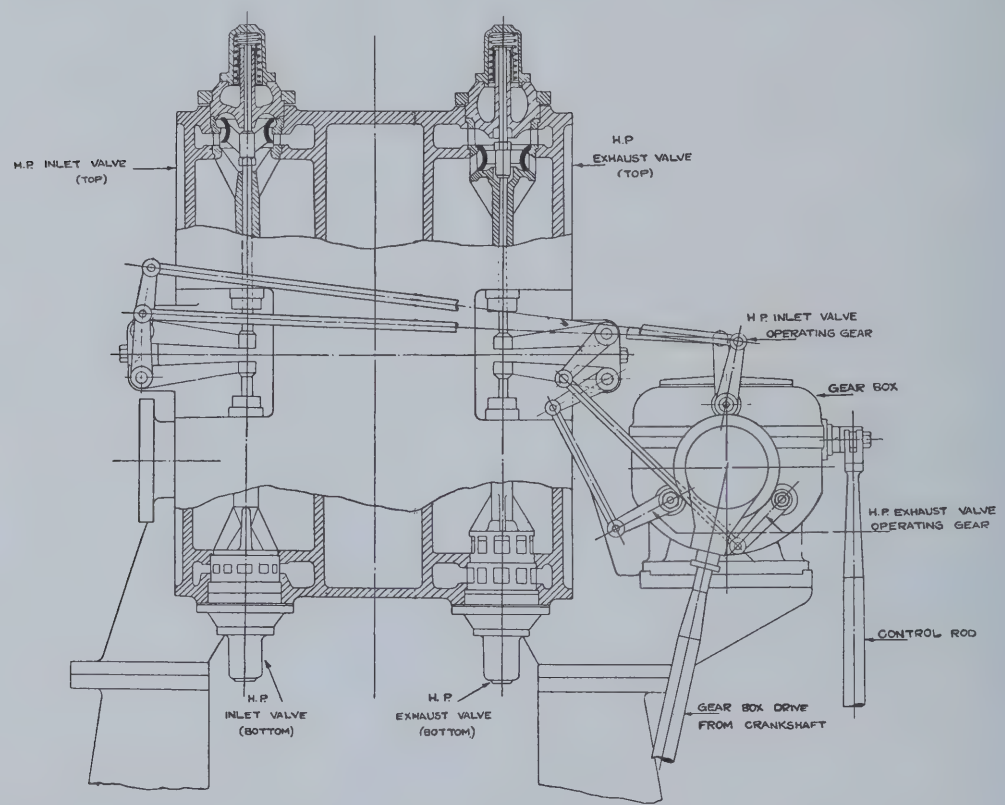


FIG. 2.—*The Beardmore-Caprotti Engine.*

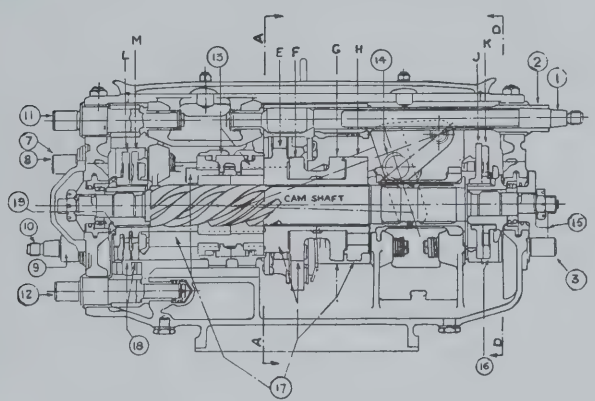
fields, F.O.B. Glasgow, both of which are quite suitable for pulverising, and the figures per ton are 8s. 6d. and 9s. 6d. respectively. The cost of pulverising varies with the degree to which pulverisation is carried, but with 80 to 85 per cent. pulverised so as to pass through 180 mesh, the power required per ton is about 14 to 15 kilowatts. With pulverised coal, ideal combustion is reached, because the fuel and oxygen from the air can be heated and intimately mixed in the correct proportions, and that the excess air is reduced to a very small amount will be realised, when it is pointed out that the percentage of CO_2 in the exhaust funnel gases of a " Woodeson " boiler, fired with pulverised coal, is about 16 per cent., as recorded during an experimental trial, at which the author was present. Its adoption will also reduce hand labour to a minimum.

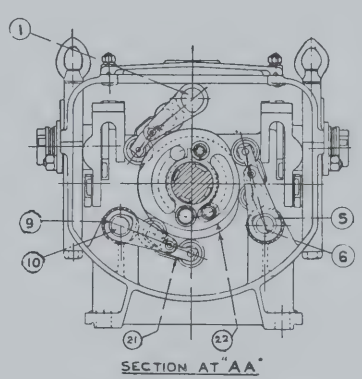
SEARCH FOR ECONOMY IN STEAM-DRIVEN VESSELS.

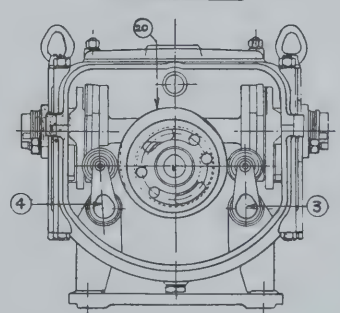
No matter how efficient the steam raising part of the marine installation may be, the economical use of fuel does not end with the boiler, but depends upon every link in the chain of efficiency being sound. The effective use of the steam produced depends upon the design of the engine. Higher pressures and higher superheat both improve engine efficiency, and to produce these features satisfactorily, the boilers

will require to be of the water-tube type. Now, marine engineers, especially those who man the tramp type of cargo steamers, and their employers have not taken kindly to geared turbine machinery. Trouble has been experienced with double reduction gearing, and it is still under a cloud, although the reasons for the early failures are now known and can be easily avoided. Single reduction gearing is not so suitable for the slow cargo vessel, and in spite of efforts to introduce improvements in steam reciprocating engines, the only alternatives for the cargo shipowner that he knows well, are the Diesel engine and the triple-expansion slide valve engine.

There is, however, another reliable type of steam engine, which the cargo shipowner would do well to exploit, namely, the triple-expansion or double-compound drop-valve steam engine, which shows considerable improvements in steam consumption over the ordinary slide-valve engine. This drop-valve engine is of the slow running type, is directly connected to the propeller shafting, has the familiar characteristics of the triple-expansion slide-valve engine, all the working parts are visible and easily accessible, and the complication of forced lubrication is not necessary. Continental owners are obtaining great satisfaction from the double compound Lentz engine, the economy being much improved and reliability being as sound







BEARDMORE-CAPROTTI GEARBOX.

1.—Solid shaft operates H.P. cylinder top end inlet valve.
2.—Hollow shaft operates H.P. cylinder bottom end inlet valve.
3.—Shaft operates H.P. cylinder top end exhaust valve.
4.—Shaft operates H.P. cylinder bottom end exhaust valve.
5.—Hollow shaft operates L.P. cylinder top end inlet valve.
6.—Solid shaft operates I.P. cylinder bottom end inlet valve.
7-8.—Shafts operate I.P. cylinder exhaust valves.
9.—Hollow shaft operates L.P. cylinder top end inlet valve.
10.—Solid shaft operates L.P. cylinder bottom end inlet valve.
11.—Shaft operates L.P. cylinder top end exhaust valve.
12.—Shaft operates L.P. cylinder bottom end exhaust valve.
13.—Inlet cam scrolls. Position of scrolls on camshaft regulated by movement of crankshaft in gearbox.
14.—Double-throw crankshaft operated from platform by hand gear. Cranks connected by rods to sleeves on inlet cam scrolls.
15.—Drive from vertical shaft connected by gearing to main engine crankshaft cam shaft revolves at engine speed.
16.—H.P. cylinder exhaust cams loose on camshaft. Cams driven independently by means of appropriate sleeves. Cam J driven by cam H. Cam K driven by cam G.
17.—H.P., I.P. and L.P. steam inlet cams loose on camshaft. Cams driven by scrolls through rods.
18.—L.P. and I.P. cylinder exhaust cams loose on camshaft. Cam L driven by dog on camshaft. Cam M driven in similar manner to cams J and K.
19.—Cam driven by dog keyed to camshaft.
20.—H.P. cylinder exhaust cams.
21.—Swinging beams with staggered rollers.
22.—Inlet cams.

FIG. 3.
The Beardmore-Caprotti Gearbox.

as the slide-valve engine. The drop valves and gear enable reversing to be easily accomplished by hand, and the poppet valves render the engine capable of using steam as highly superheated as can be used in a turbine, in fact, under the same conditions of pressure, temperature and vacuum as a turbine, and up to about 5,000 I.H.P. per engine, the steam consumption for this engine is claimed to be equal to the turbine engine. It has the additional advantage of being a slow running engine, and takes up less space than a triple expansion engine of the same power.

The triple expansion engine of the drop-valve type is represented by the Beardmore-Caprotti engine.

In the Beardmore-Caprotti marine engine, distribution of the steam to the cylinders is effected by means of poppet valves controlled by cam-operated levers, these taking the place of the usual eccentrics, slide valves and link motion. (See Fig. 2.)

There are four poppet valves to each cylinder, one admission and one exhaust valve being arranged at the top end of the cylinder, and similar valves at the bottom end of the cylinder. The valves, which are of the double beat type, are operated by tappets fitted to the ends of rocking levers, which latter are, in turn, operated by cams arranged on a rotary camshaft, the cam gearing for the complete engine being contained in one gear-box (Fig. 3) situated near the cylinders, and at the forward end of the engine. A shaft, driven by bevel or spiral gearing, connects the gearbox to the engine crank-shaft, from which the drive is taken. The relative movement of the cams is controlled by a simple hand gear led to the starting platform, the valves, being of the balanced type, require very little power for their operation and consequently all the gear is comparatively simple and of light construction. Also, the cam gearing runs in an oil bath, and is, therefore, running under ideal conditions.

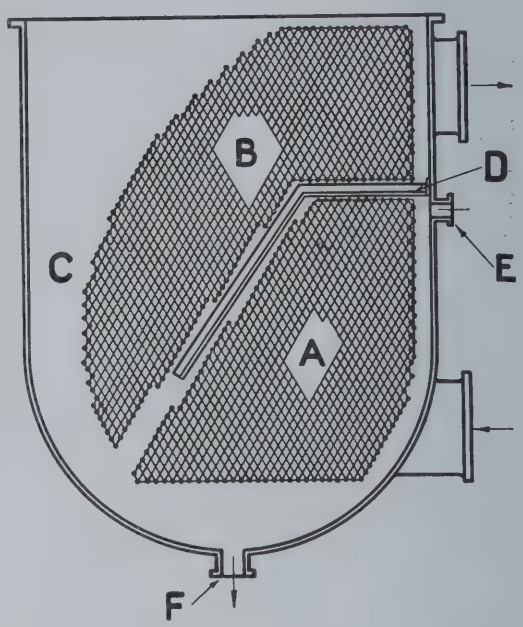


FIG. 4.—*The Weir Regenerative Condenser.*

The most important advantage of the Beardmore-Caprotti gear is in respect of reduced steam consumption, the saving being about 10 per cent. compared with an engine employing the ordinary type of valves. The power required to operate the gear is less, as is also the wear and tear; this tends to increase the effective power of the engine.

One of the objections to the use of superheated steam in the ordinary reciprocating engine is the difficulty of lubricating the slide valves. By the use of poppet valves, this trouble is eliminated, and the economy which results from the use of superheated steam can thus be realised.

Due to the elimination of the link motion, the overall length of the engine is reduced by approximately 25 per cent., while a considerable saving in weight is also effected. Otherwise, the main features of the ordinary marine engine remain.

THE ECONOMICAL STEAM-DRIVEN CARGO VESSEL.

Auxiliary machinery is notoriously expensive in steam consumption. For instance, the steam consumption of the auxiliary machinery on the "King George V." was actually 20 per cent. of the total consumption of the main machinery. Something better must be done to reduce this extravagant consumption, and it is proposed to arrange the machinery of the economic cargo vessel somewhat on the following lines.

The main engines are to be of the drop, or poppet valve type, either double compound, or triple expansion, supplied with steam from the boiler at 275 lbs. per square inch pressure and a total steam temperature of 650° F. Means are to be adopted to dry the steam at the intermediate expansion stages, and the main engines are to exhaust to a low-pressure turbine which is to drive a dynamo to supply current for operating all the auxiliary machinery electrically, except the feed pump. A small high-pressure turbine is to be arranged for driving the dynamo when manoeuvring, or when the vessel is in port. The low-pressure turbine is to exhaust to a regenerative condenser of the "Weir" type, so as to retain as much heat as possible in the condensate, and the condensate is to be heated by steam tapped from the L.P. receivers.

There is to be one water-tube boiler working at 275 lbs. per square inch pressure, fitted with superheater tube elements to produce a total steam temperature of 650° F. at the main engines, air heating elements and a feed heater to obtain the full benefit of the heat in the exhaust funnel gases. The boiler

S.S. 3,000 S.H.P. Cargo Vessel. 10,000 tons D.W. 11—11½ knots.

Machinery—

(1) Triple expansion slide valve engines with saturated steam and coal-fired cylindrical marine boilers with forced draught.

(2) Four-cycle, single-acting Diesel engine, with electrical auxiliaries.

(3) Triple expansion or double compound reciprocating engine with poppet valves working at 275 lbs. per square inch boiler pressure, and total steam temperature of 650° F. Auxiliaries driven electrically by exhaust steam turbine operating dynamo.

	Type 1.	Type 2.	Type 3.
Power and revolutions	3,450 I.H.P. 75 r.p.m.	3,000 B.H.P. 110 r.p.m.	3,450 I.H.P. 90 r.p.m.
First cost of machinery	£38,000	£68,000	£45,000
Weight of machinery—tons	630	730	550
Fuel per I.H.P. per hour, all purposes—lbs.	1.7	0.45	1.175
Fuel per day at sea—tons...	62.8	14.5	43.5
Fuel per day in port—tons	6.5	2.5	4.0
Number of days at sea	250	250	250
Fuel consumed at sea—tons	15,700	3,625	10,875
Number of days in port	115	115	115
Fuel consumed in port—tons	747	288	460
Total fuel per annum—tons	16,447	3,913	11,335
Cost of fuel per annum	£21,381	£17,120	£9,068
Cost of lubricating oil per annum	£263	£600	£263
Engine room wages and food	£4,240	£3,100	£3,300
Fresh water	£270	£21	£240
Charges 18½ per cent. of cost	£7,000	£12,600	£8,325
Total annual charges	£33,154	£33,441	£21,196

TABLE SHEWING EXTRA OR LESS FREIGHT CARRIED FOR TYPES 1 AND 2 COMPARED WITH 3.

A. Length of voyage, 11 days; Voyages per annum, 22.7; Freight rate, 14s.
B. „ „ 18 days; „ „ 13.9; „ 20s.
C. „ „ 25 days; „ „ 10.0; „ 26s.

	A.			B.			C.		
Type of machinery	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3
Fuel carried—tons	816	189	565	1,260	290	870	1,700	392	1,175
Water carried—tons ...	88	10	66	144	17	108	200	23	150
Weight machinery—tons...	630	730	550	630	730	550	630	730	550
Total weight carried—tons	1,534	929	1,181	2,034	1,037	1,528	2,530	1,145	1,875
Surplus weight for freight—tons	Minus 353	Plus 252	—	Minus 506	Plus 491	—	Minus 655	Plus 730	—
Extra or lower earnings ...	Lower £5,600	Extra £4,000	—	Lower £7,040	Extra £6,820	—	Lower £8,500	Extra £9,480	—
Annual Charges—No. 1				£33,154					
Annual Charges—No. 2				£33,441					
Annual Charges—No. 3				£21,196					
Annual Charges—No. 1 +lower earnings ...	£38,754	—	—	£40,194	—	—	£41,654	—	—
Annual Charges—No. 2 less extra earnings ...	—	£29,441	—	—	£26,621	—	—	£23,961	—

is to be fired with pulverised coal, 80 per cent. of which will pass through a 200 mesh, and there is to be one working and one standby pulveriser, driven by electric motors. The coal from the bunkers is to be handled by an electrically-driven worm feed gear, suitably controlled, and provision is to be made to enable the coal to be hand fed to the pulveriser hopper, if required.

The features of this installation, which all tend to improve economy, are :—

(1) Poppet valve engines.
(2) Electrically-driven auxiliaries operated through turbine and dynamo by exhaust steam from the main engines.
(3) Drying the partially expanded steam in the inter-expansion stages.
(4) Retaining as much heat as possible in the condensate.
(5) Boiler fired by pulverised coal.

A regenerative condenser of the " Weir " type is shewn in Fig. 4. The condenser is underhung and occupies a similar space to that of normal design. B is the second pass and A is the first, C a clear passage of gradually reducing area extending fully to the bottom of the condenser, so that exhaust steam passes right down to the bottom. D is the baffle plate, so arranged that the air and vapour flow in the top portion of the first pass A is ascending. E is the air suction branch, and F the condensate suction branch.

This arrangement gives a complete regenerative effect at all loads by the steam penetrating to the bottom of the condenser, and thereby reheating the colder condensate which rains down from the tube nests. The latter portion of the steam flow being ascending, the surface functioning as an air cooler is self-adjusting, thereby presenting the maximum surface for the condensation of steam at all values of air leakages. The condensate being at vacuum temperature, contains no air in solution and is, therefore, non-corrosive and ideal for feeding into water-tube boilers.

It is estimated that if coal averaging 11,500 B.Th.U.'s per lb. were used for pulverising, which could be purchased F.O.B. Glasgow at 9s. 6d. per ton, the total coal consumption per I.H.P. for all purposes would not exceed 1.175 lbs. on service.

In order to show what the present practice is on board ship in many cargo machinery installations, and what is possible with the foregoing proposals, three balance sheets have been prepared, each showing engines of 3,000 S.H.P. of different types, suitable for propelling a 10,000-ton D.W. cargo vessel at 11—11½ knots.

(1) An ordinary triple expansion saturated steam engine, with cylindrical boilers, fired with coal under forced draught conditions.
(2) A Diesel engine of four-cycle S.A. type.
(3) A poppet valve engine installation embodying the five features already described.

Note.—Fuel costs have been averaged, half being assumed purchased in this country, and half abroad.

The vessels have been assumed to spend 250 days at sea and 115 in port, and a further table is shown embodying the extra or less freight carried for each type for voyages of differing lengths, taking No. 3 type as basis.

The savings in respect of No. 3 type are clearly demonstrated, and even on 25-day voyages, the savings of the pulverised fuel poppet valve type are over £2,700 per annum.

It has also been assumed that the coal purchased abroad for pulverising has to be shipped from this country, but if pulverised coal can be efficiently burnt, the foreign coal of inferior quality can be much more readily utilised, and can be purchased at a cheaper rate than that assumed. This will still further increase the savings. For instance, Indian coal is very difficult to burn on an ordinary firegrate, but will become much more marketable if pulverised, then the cost should not exceed the cost of mixed " pearls " and " gum " in this country.

While it is not expected that all these features will be adopted immediately or in their entirety, yet the suggestions serve to indicate the line of thought which shipowners and their advisers should be prepared to consider in their effort to reach the maximum fuel economy possible. The trade of the British nation was built up on coal, and the long looked for revival in trade will only arrive when the coal industry has once more been put on a healthy basis.

Chapter 7.

STEAM RAISING IN LOCOMOTIVE BOILERS.

By E. C. Poultney, O.B.E.

The subject of fuel for locomotives, if considered in a general sense, would assume considerable proportions owing to the many varied conditions governing the choice of fuel which can be economically utilised. Fortunately, however, so far as Great Britain is concerned, the matter is relatively simple, as, commercially, coal is the only fuel that is readily available. Moreover, it is usually of good quality, and of such a character that, broadly speaking, only one type or form of fire-box is in evidence in British locomotive practice, the features of which will be discussed later.

In actual practice, several factors must be taken into consideration when selecting the coal which will give the best results commercially, under the average prevailing locomotive operating conditions. The principal points to be noted are as follow:—

(1) The values of various grades of coal should be based upon their relative heat contents, *i.e.*, value per B.Th.U. A cheap fuel may not be the least expensive to burn.

(2) Locomotive coal cannot be judged solely upon its calorific value, although this should be high. Suitability can only be determined by tests carried out under actual running conditions. Certain practical considerations, such as friability, caking, and clinker formation, have to be taken into account.

(3) The method of coaling locomotives has an important bearing on the description of coal suitable, and on the ultimate cost. The softer grades of coal may be put on the tender by hand without being unduly broken up, but the same coal, if dealt with by a mechanical coaling plant may lose an appreciable amount in the way of dust, and the formation of small particles, so that the ultimate consumption may be raised through an increase in smoke-box cinders, and losses through coal being thrown out of the chimney when running, etc. Thus, the economic value of an otherwise good fuel, may be lowered.

(4) As coaling plants are of value in lowering bunkering costs, when large numbers of locomotives have to be coaled, the coal used at such engine terminals may be different from that used at smaller sheds, where coaling is carried out by hand.

(5) Coal stacked for storage must not be liable to spontaneous combustion, loss of volatile matter, or to crumbling.

(6) The proximity of coalfields also influences the choice.

The coal used for locomotive purposes in this country, is specified as "lump coal," and is, roughly, of two kinds—bituminous and semi-bituminous. The former is most extensively employed, the grades considered most suitable being hard; break up readily, make very little small coal and dust, and can be forced to high rates of burning.

South Wales steam coal, often called "blind" coal, is also used to a small extent. This approaches anthracite, but is higher in volatile matter and lower in carbon. It is hot, and is excellent steaming fuel, but requires careful handling, being slower burning, and igniting less readily than fuels of the bituminous kind. Welsh coal is also rather soft and friable, but, if carefully handled, especially by the firemen, very good steaming results are obtainable.

A comparison may be made of the constituents of Yorkshire and Welsh steam coal, found to be suitable and to give satisfactory results in locomotive service.

Coal.	Welsh.	Yorkshire.
Moisture, per cent.	1.0	2.6
Ash, per cent.	9.5	5.5
Volatile matter, per cent.	14.4	34.4
Fixed carbon, per cent.	75.1	57.5
	100.0	100.0
Calorific value, B.Th.U.'s	14,000	13,900

The above, covers two different qualities of coal which formed the subject of some complete tests carried out on the Southern Railway, under the direction of the Chief Mechanical Engineer, Mr. R. E. L. Maunsell. These tests were made, in order to develop certain specific and practical points bearing on the general question of locomotive coal consumption. They are given as under: (1) to compare the results obtainable with typical Welsh and Yorkshire coal; and (2) to ascertain whether, passing these fuels through a coaling plant, would make any appreciable difference in the consumption. In all, 5 series of trials were made, each consisting of 3 trips between London and Salisbury, 167.5 miles for the double journey. The single trip is 83.75 miles, and the times allowed, between 92 and 93 minutes. The total coal consumption, per 1,000 ton-miles, was as follows:—

Series.	Mean Consumption. lbs.
(1) Welsh coal from plant	96.0
(2) ,, ,, ,, wagon	84.3
(3) Yorkshire ,, ,, ,, ...	88.6
(4) Welsh ,, ,, plant	80.6
(5) Yorkshire ,, ,, wagon	76.7

In all cases, the steam was raised from cold water, and further, the last two consumptions quoted, appertaining to series 4 and 5, give the average of the 3 runs in each series, and are for trains not steam-heated. All other runs were for steam-heated trains.

For the first series, the high average consumption of 96.0 lbs. per 1,000 ton-miles is stated to be due to the coal on the first trial being abnormally dusty. Comparing Welsh coal from the wagon and from the plant, the consumptions are 84.3 (series 2) and 80.6 lbs. (series 4) per 1,000 ton-miles. The coaling plant appears to have caused a certain amount of crumbling, and breaking up of the fuel, and this, in turn, causes losses in unburned coal, or only partially consumed coal; this is seen to be the case when the quantity of cinders taken from the smoke-box is noted. Welsh coal from the wagon (series 2), gave the following results: cinders, from smoke-box, averaged 210 lbs., and for series 4, 375 lbs., so that the smoke-box contents, as a percentage of the coal fired, was, respectively, 3.36 and 5.87 per cent. For the Yorkshire coal, the smoke-box ash, as a percentage of the coal fired, varied from 2.35 to 2.11 for series 3 and 5 respectively.

Attention has already been directed to the fact that practice on British railways is to use rather large coal for locomotive requirements, and this is found to give satisfactory results with the type of fire-box and on service conditions to be met with here.

Necessity for the economic use of fuel.

There are certain very clearly defined reasons, why the economic use of coal in railway operation should receive serious attention. These are: (a) The greatly increased cost of coal; (b) the importance of reducing locomotive fuel consumption, and thus operating costs; (c) the desirability of improving the performance in order to produce greater hauling capacity, without materially increasing the size and weight of locomotives.

In briefly reviewing these several items, the first two are, of course, fully recognised. The manner in which the enormous annual fuel bills of the great railway systems of this country have increased in recent years is common knowledge, and definite financial gain may be accomplished, by economies in the coal consumption of motive power. Out of every hundred scoops of coal charged into the fire-box of the average locomotive, only about six do useful work on the drawbar behind the tender, and in general, for every 100 heat units expended, but 6 reappear as available energy to move the train. In what follows, an attempt will be made to indicate the means which may be taken to modify, to some extent, this great waste, improve the economic performance of the steam locomotive, and also increase the energy output per ton of locomotive weight. In order to accomplish this, an analysis will be made of the process of steam production in the normal type of locomotive boiler, the essentials governing efficient working noted, and such suggestions as may be necessary for the further economic development of the locomotive engine, presented.

STEAM GENERATION.

The principal features of the multitubular type of boiler common in locomotive service, comprise the furnace, or fire-box, with the grate, the barrel portion containing the tubes through which the gases, liberated by the action of the fire-box, pass to the smoke-box which contains the blast pipe exhausting the steam from the engine, and which, together with the chimney arrangements, forms the means for creating the draught for moving the combustion air through the fuel bed. In addition, there is an ashpan under the firebars provided with damper arrangement of simple construction, and a brick arch built across the fire-box, extending back from the tube plate of the latter. The fire-box proper is contained within an outer casing of roughly the same general shape, and is entirely surrounded by water except, of course, at the bottom where the grate is fixed, and at the firehole and points of entry of the tubes in the tube-plate.

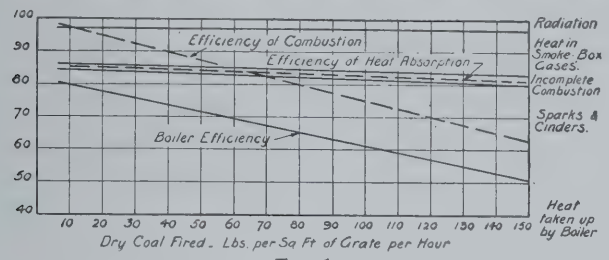

Efficiency of Combustion
Efficiency of Heat Absorption
Boiler Efficiency
Radiation
Heat in Smoke Box Gases.
Incomplete Combustion
Sparks & Cinders.
Heat taken up by Boiler
Dry Coal Fired - Lbs. per Sq Ft of Grate per Hour

FIG. 1.

The process of combustion takes place in the following manner:—Coal is charged into the fire-box, whilst at the same time air is admitted through the ashpan, firebars and fuel bed, and also, to some extent, through the fire-hole door opening. Of the heat thus generated, part is radiated direct to the fire-box heating surfaces. The remainder raises the temperature of the fire-box gases, and by them is carried out of the fire-box and through the tubes to the smoke-box, where such heat as remains after passing through the tubes is ejected through the chimney, along with the exhaust steam from the engine cylinders, which forms the draughting means to which reference has already been made. The rate at which the air is supplied, controls the rate of combustion, the fire-box temperature, the rate at which the heat is given up in the tubes, the smoke-box temperature, and, in fact, the whole action, not only in the fire-box, but in the boiler, as a whole. To ensure complete combustion, two conditions must be satisfied, namely: (1) High fire-box temperatures; and (2) intimate contact between the air and the heated fuel. With coal as fuel, it is necessary to have ample grate area so that sufficient air may pass through the fuel without its flow being so concentrated as to carry an excessive amount of fuel off the grate, and out of the fire-box before it can be burned. Also with coal of the bituminous kind, ample volume is required, to provide for the proper mixing of the air with the gases given off by the burning coal. This latter point is of great importance, and is worthy of much attention on the part of designers.

The maximum rate of firing for any given proportions of grate and fire-box volume is determined by the amount of air that can be admitted per sq. ft. of grate area, without carrying out of the box an unduly large amount of fuel. In other words, the rate of working will be dependent upon the quality of the fuel used. The reason why the coal largely employed in Britain will stand such high rates of firing, is due to the large size of the coal as fired, and to its relative hardness. Even so, the writer believes that economies might be secured if larger grates were employed than those generally in evidence. Anyone who has seen the accumulations of unburned fuel in the smoke-boxes of locomotives used in heavy services, must be impressed with this fact. This loss of fuel increases rapidly with the rate of firing, and grate area is a controlling factor which must not be overlooked.

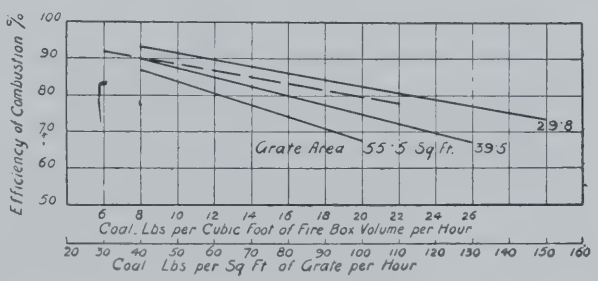

Efficiency of Combustion %
Grate Area 55·5 Sq Ft.
29·8
39·5
Coal. Lbs per Cubic Foot of Fire Box Volume per Hour
Coal Lbs per Sq Ft of Grate per Hour

FIG. 2.

Transfer of heat to heating surfaces.—The fire-box heating surfaces receive practically all their heat, by radiation, whilst on the other hand, the tubes and flues and the superheater elements receive heat by direct contact with the combustion gases passing over them.

The amount of heat radiated to the fire-box heating surfaces, depends on the difference in the temperature between the radiating surfaces and the heating surfaces, and upon the area, or extent of the

radiating surfaces. In a locomotive fire-box, the radiating surfaces consist of the grate when covered with live coal, the luminous flame, and also the heated brickwork of the arch.

An increase in fire-box heating surfaces will have little effect on fire-box evaporation, unless, at the same time, there is an increase in the surfaces radiating heat. Adding to fire-box surfaces, however, also adds to the volume, and if the increased volume is completely filled with flame, then at the same time, as the heating surfaces are increased, so also will be the radiating surfaces, and the larger heating surfaces will add, proportionately, to the evaporating power of the fire-box. With long flame, or bituminous, fuel this is of importance, and further, the longer flame-ways thus provided, assist materially in the effective burning of the small particles of fuel which are always lifted in greater or smaller quantities from the grate. Consideration of the foregoing indicates why, for short-flame, semi-bituminous, and anthracite coals large fire-box volume is of less importance, and a large grate offering a large radiating surface, and also enabling the fuel to be burned more slowly, is to be preferred.

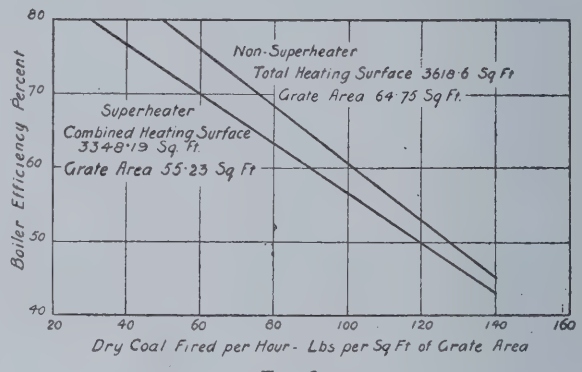


FIG. 3.

The function of the tubes and flues is to absorb the heat from the products of combustion liberated by the fire-box. They accomplish this by direct contact with the gases as they pass through. To be effective, it is desirable that tubes be made of small diameter, as the gases should be divided into thin streams. Tube efficiency increases as the diameter decreases and the length increases, but not exactly in direct proportion to the length. With each successive increase in length, heat absorption diminishes, and there comes a stage when any further increase in length, adds comparatively little to the efficiency. It seems probable that tube efficiency can best be improved by reducing diameters rather than increasing lengths. In practice, however, while it is no doubt true that small tubes would be most effective in extracting the heat from the gases, it is also true that the smaller passage ways may easily become filled up with cinders, etc., and for these reasons small tubes are impracticable. For given grate and fire-box conditions, short tubes promote rapid steaming in proportion to the draught available, but at the same time, give low efficiency owing to the higher smoke-box temperatures. It would therefore seem that the problem is to so proportion tube diameters and lengths that low smoke-box temperatures may be obtained without, at the same time, necessitating an ordinately high draught pressure for moving the weight of gases required to meet the desired steaming capacity.

The writer believes the subject of obtaining the best fire area through the tubes and flues to be of importance, and of the size and form of the tubes remain the same, the relation between fire area, heating surface, evaporation and efficiency may be stated in the following manner:—

(1) Heating surface increased, without an increase in fire area, means an increase in length. This leads to greater boiler efficiency. The evaporation is, however, increased only slightly, owing to the difficulty of moving a greater amount of gas through the boiler, due to the higher resistances offered.

(2) An increase in fire area, without an increase in heating surface, means more tubes and less tube length. Any extensive change in this direction will increase considerably the evaporative capacity, because the larger fire area and the shorter tubes will enable a greater amount of air to be passed through the boiler with the same draught. The shorter tubes will lower efficiency, but the boiler will steam more freely.

Temperatures, Heat Losses and Boiler Efficiency. The foregoing presents a general idea of the fundamentals underlying the working of the locomotive boiler. It is now proposed to remark upon relative fire-box and smoke-box temperatures, heat distribution, and working efficiency. If the temperatures in the fire-box and smoke-box are examined for increasing rates of combustion, it will, in general, be found that there is, throughout the full range of firing, a nearly constant difference between the corresponding fire-box and smoke-box temperatures. This points to the fact that, whatever the weight or quantity of gases liberated by the fire-box, the tube surfaces take up a fixed amount of heat from each cu. ft. or each lb. of gas passing over them. Actually, the transfer of heat, by gas contact or conduction,

increases as the production of the gases becomes greater, and this is the reason why it is possible to obtain the large evaporations and the high powers delivered by the locomotive boiler. The distribution of heat

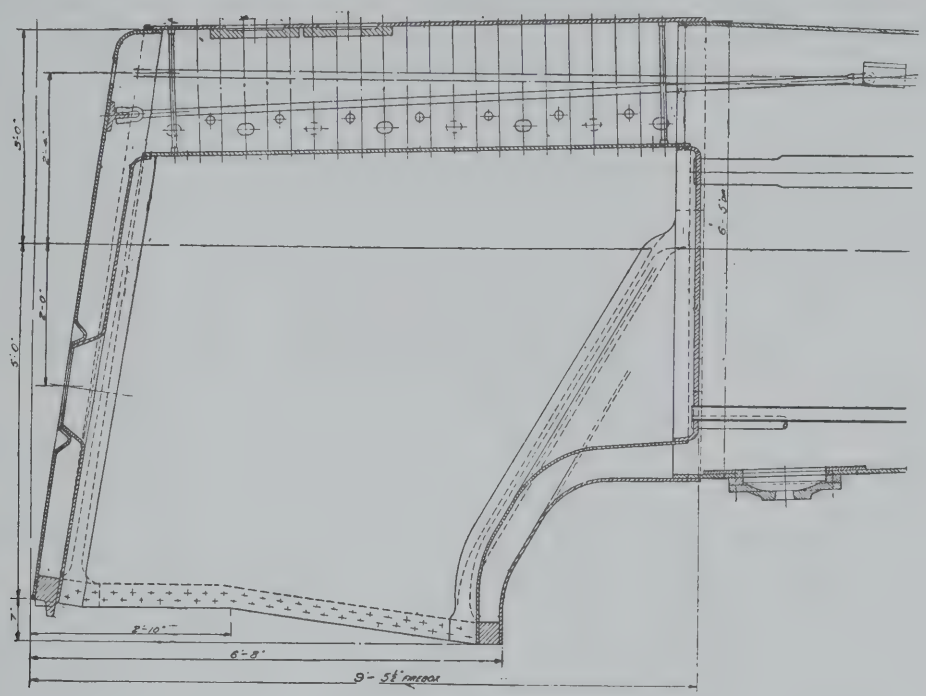


FIG. 4.

in the working of the boiler is shown by Fig. 1, which illustrates, in a general manner, the heat balance, and the principal causes of loss will readily be seen.

These balances separate the heat in the fuel into five different parts, namely :—(1) Heat utilised in generating and superheating the steam. This measures the overall boiler efficiency. (2) Heat lost by external radiation. (3) Items 1 plus 2 give the total heat taken up by the heating surfaces. (4) Heat lost in the sensible heat in the smoke-box gases. (5) Items 1, 2 and 4 together make up the total heat produced by the combustion process. (6) Heat lost by incomplete combustion—the production of CO. (7) Heat lost by cinders and sparks. (8) Items 6 and 7, represent the amount of heat lost by imperfect combustion.

How these various losses are related in magnitude to each other is shown in Fig. 1 and, in addition, the actual combustion and heating surface (absorption) efficiencies are indicated by the broken lines which shew that the locomotive boiler transfers across its heating surfaces from 85 to 83 per cent. of the heat actually available at firing rates, between 10 and 150 lbs. of dry coal, per sq. ft. of grate, per hour, and that between these limits the efficiency of combustion, which is high at low rates of firing, falls to little more

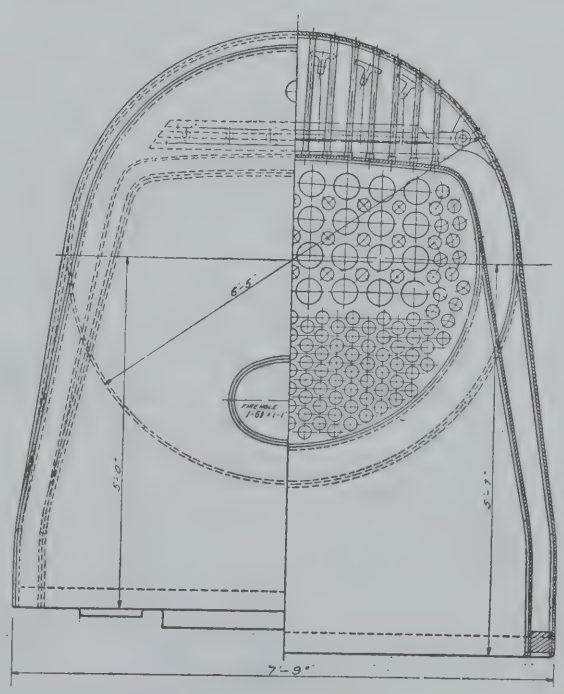


FIG. 5.

than 60 per cent. when 150 lbs. of dry coal are fired per sq. ft. of grate, per hour. Heating surfaces are uniformly efficient, but fire-box conditions are capable of much improvement.

Grate Area and Fire-box Volume. The overall or boiler efficiency is represented by the lowest line in the plot, and it will be seen that between the firing rate limits given, the percentage of the heat units fired which re-appear in the superheated steam, vary from 80 to 50 per cent. This fall in efficiency stresses the importance of grate area, and while not offering conclusive proof that added fire-box volume would be advantageous, investigations made and results given by Mr. Lawford H. Fry at a meeting of the American Railroad Association, Montreal Convention, 1927, show that the efficiency of combustion in relation to grate area and fire-box volume, is higher for a given firing rate in the case of a boiler having a fire-box of large volume in proportion to the grate, than in one having a smaller volume grate ratio.

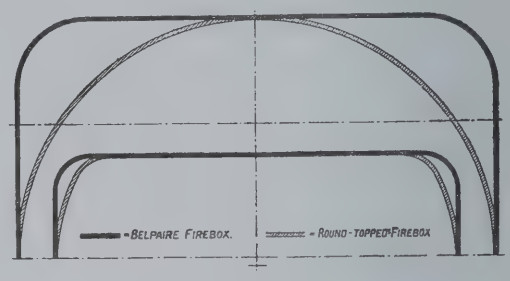


FIG. 6.

In this connection, Fig. 2 is interesting, as showing the influence of volume on combustion efficiency when bituminous coal is the fuel employed. The tests were made with one boiler, the grate area being restricted by being successively reduced from 55.5 to 39.5, and finally to 29.8 sq. ft. It will be noted that raising the firing rate from 100 to 130 lbs. maintained a constant combustion efficiency of 68 per cent., and that at a firing rate of 150 lbs. the efficiency was 73, as against 68 per cent. at 100 lbs. With a firing rate based on the quantity of coal fired, per sq. ft. of grate, per hour, combustion efficiency is least with the largest grate ; this, of course, is only another way of saying that the greater the quantity of fuel fired into a fire-box of given size (volume), the less perfect will be the combustion.

Evidently, volume is an important factor, and the truth of this is well established by the broken line in the graph which shows that, independent of grate surface, if the rate of firing is based on the volume, the efficiency results for all three grates fall on one straight line ; in other words, if a given quantity of coal is fired per hour, the fire-box being of given proportions, then independent of the grate area the combustion process will be equally complete.

The Brick Arch and Thermal Syphons. All locomotives in this country have an arch of brickwork built in the fire-box. The arrangement is constructed over a framing afterwards removed, and rests on studs tapped into the side sheets. Usually, the arch extends back from the tube plate about one half of the length of the box, the object being to baffle the flame, and prevent the combustion gases from passing out of the box through the tubes without first becoming mixed, and, further, to deflect the small particles of fuel and materially decrease losses through unburnt coal being carried through the tubes to the smoke-box.

The Pennsylvania Railroad, of America, has made tests with a boiler with, and without, an arch. The tests proved that, at maximum rates of firing, the equivalent evaporation, per hour, with the arch was increased from 67,000 to 79,000 lbs., approximately, thus indicating a gain in capacity of about 11.7 per cent. for a given amount of coal fired, per hour. Without the arch, 10,540 lbs. of coal produced an equivalent evaporation of 67,000, and with it, the evaporation was 79,000 lbs., so that the water-coal ratios obtained were respectively 5.84 and 7.47 lbs. The Security sectional arch, carried on arch water tubes, was the type used.*

The Thermal syphon is a device which has come into use largely on several lines in the United States. Each syphon takes the place of an arch tube, giving a much larger heating surface, and provides, at the same time, a substantial brace to the crown, while protection is also given against over-heating by low water. The fire-box heating surface can be increased from 10 to 40 per cent., according to the number of syphons fitted.

*Pennsylvania Railway. Test Plant Bulletin No. 30.

The Superheater.—Modern locomotives, intended for main-line working, are always fitted with a superheater, and from the point of view of economy in fuel consumption, this apparatus is the most important improvement yet introduced. At the present time, total steam temperatures of about 650° F., are the maximum usually employed. Taking a steam temperature of 650°, and a boiler working pressure of 180 lbs. per sq. in., the superheat added is 271°, and while this amount of superheat has been conducive to high economies in coal and water consumption, it is certain that still higher superheats would be beneficial.

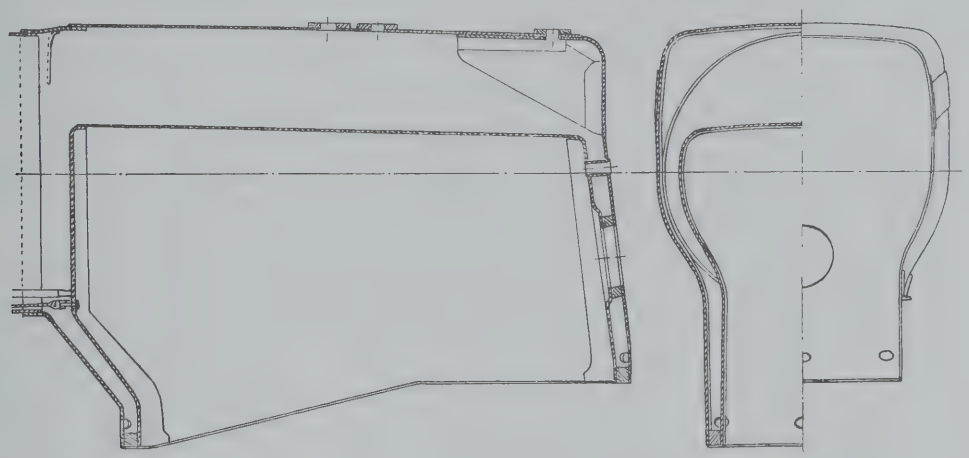


FIG. 7.

Probably, however, changes will have to be made in the type of valve used for the steam distribution in the cylinders, before higher superheats, however desirable, become common.

The action of the superheater in taking up heat from the gases passing through the flues is similar to that of the boiler tubes, and the more the boiler is forced, and the higher the evaporation, the higher will be the superheat. The superheat only ceases to increase when the evaporation reaches the maximum. This is a valuable characteristic of superheater locomotives, and explains why they can be worked harder than locomotives employing only saturated steam.

The addition of a flue tube superheater displaces a certain amount of evaporative heating surface, and thus on the basis of the coal fired, the efficiency is lowered slightly, Fig. 3. At the same time, however, the cylinder efficiency is vastly improved, and so also is the boiler performance when boiler efficiency is measured against the I.H.P. developed.

Feed-water Heating.—The subject of preheating the boiler feed has been under consideration for many years past. It was practised in the early days of locomotive development, but, in general, has made little progress, due to many difficulties which prevent, or have prevented, it from giving the result expected. At present, the system most in evidence is that in which exhaust steam is the means employed for feeding the water into the boiler. The heat thus imparted is obtained by utilising part of that which would otherwise be lost at the chimney. Actually a proportion of boiler steam is also required. Feed heaters of the pump and heater type, the latter being of the open or closed pattern, have recently come very much into prominence, especially in Germany and North America.

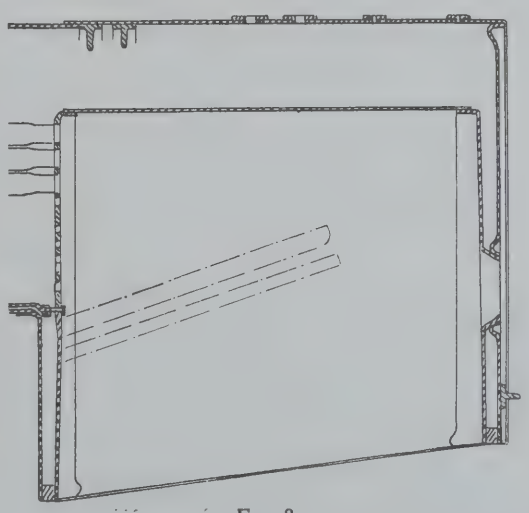


FIG. 8.

Like the superheater, the feed heater may be looked upon as an adjunct to the boiler, the difference being that whilst that superheater detracts to a small extent from the efficiency of the boiler, but improves considerably the steam action in the engine cylinders, the heater on the other hand increases the boiler

capacity, proportional to the amount of heat which it returns to it by reason of the hot feed, and increases the efficiency for the same reason, as well as because of the decrease in the fuel required to effect a given steam production.

From the foregoing, it will be realised that for a given power the heat transfer across the heating surfaces will be less, and that in consequence, the degree of superheat imparted to the steam will be lower. Tests, have, however, shown that there is little or no difference in the steam consumption. This is attributable to the fact that feed heaters, by condensing a portion of the exhaust steam, lower the back pressure on the pistons, thus increasing slightly the power for given conditions of cut-off and speed. Another point is that the temperature of the feed increases with the evaporation, so that, like the superheater, the value of the feed-water heater increases as the demand for power increases. This is an additional advantage.

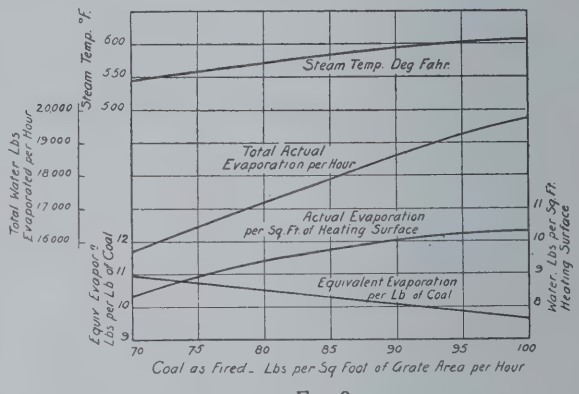


FIG. 9.

It is difficult to say, with accuracy, the amount of coal saving actually obtained by feed heating, so much depends on variables which affect the heater, and prevent the saving possible under ideal conditions. Generally, an economy of 10 per cent. should be realised. Tests have shown better results, as high as 14 per cent. being reported from trials made by the Pennyslvania Railroad, on the testing plant at Altoona, U.S.A.*

Mechanical Stokers.—At the present time, there seems little probability of mechanical firing being required in locomotive service in this country. It may be interesting, however, to refer shortly to this part of the subject. In the United States especially, but also in Canada, mechanical stokers are largely in use. they have become a necessity, owing to (1), the high sustained power required; (2) the lower grade coal used, making higher consumptions necessary; and (3) the very large grate areas common which further enhance the difficulty of hand firing.

The practical limit of hand firing is variously estimated at from 4,000 to 6,000 lbs. of coal per hour. In 1920 the American Railroad Association Committee on stokers laid down that it was necessary to fit stokers when 5,000 lbs. was the average firing rate required. It is found that evaporative efficiency is hardly so good with stoker firing as with expert hand firing, especially at the lower firing rates, though in practice, a mechanical stoker gives results equal to average hand firing, because it is easier to train firemen to operate a stoker properly, particularly when high-power engines are considered.

Advantages of Large Heating Surfaces and Grate Areas.—From a study of the boiler efficiency characteristics, set out in Fig. 1, it will be appreciated that the larger the boiler in proportion to the work it has to perform, the higher will be its efficiency.

It is found in practice that, as the rate of working of the locomotive increases, so also does the relative economy of the large boiler, and the marked advantage of a large heating surface and grate area will thus be appreciated.

BOILER DESIGN AND PROPORTIONS.

The value of fire-box volume grate area and adequate heating surfaces being recognised, there are certain very important points in connection with the design of the boiler proper, which, if not given due consideration, will offset to a greater or less degree any improvements possible by attention given to the fire-box dimensions, tube lengths and diameters, and superheater arrangements.

In general, the type of boiler used on British railways has what is called the narrow fire-box, designated thus because it extends between the frames, which are, by reason of the rail gauge, about 49 inches apart.

With the exception of a number of "Atlantic," or 4-4-2 type, engines in use on the L.N.E. Railway, and the Southern Railway, the narrow type of box was the only one in use until, comparatively, recently. These "Atlantic" engines have wide fire-boxes resting on top of the frames, the weight being taken by a

*Pennsylvania Railway Test Plant Bulletin No. 32. Tests of a Class 1.I.S. Engine with Feed Heater.

small pair of trailing wheels. During the last few years, some large "Pacific," or 4-6-2 type, passenger engines, having wide fire-boxes constructed upon the same principle, have been introduced for express passenger service on the L.N.E. Railway. These boilers, however, also include a combustion chamber, formed by extending the fire-box forward into the barrel. Fig. 4 shows this notable design in elevation, while a section through the box is given in Fig. 5. This boiler may be compared with those which follow, and the fundamental differences between the wide and narrow fire-box construction will readily be seen. The ample grate obtainable with the wide box is its chief advantage, and this is most important when low grades of coal are used, as it enables larger quantities to be burned at reasonable combustion rates.

Further, when very large boilers are required, the wide box is necessary, in order to obtain a reasonable heating surface grate ratio.

Whichever type of fire-box is employed, it is essential that the water space between the inner fire-box and the outer casing is ample. Here, the wide box has some additional advantages, because increasing the water space does not of necessity restrict the grate area, as in the case of the narrow fire-box.

The water space increases from the foundation ring level to the crown of the inner box. Here again, is an important feature. Steam rising from the heating surfaces must have easy access to the surface of the water, and owing to the cross-sectional form of the narrow fire-box, it will be evident that a considerable increase in the water spacing is desirable. The same ideas apply when tube spacing is considered. Cases have been known when better, or equal, steaming has been attained by taking out tubes, thus allowing a less restricted path for the steam globules.

Water-line area is a feature of importance, and especially so in the vicinity of the fire-box. Fig. 6 shows clearly how this may be increased by using the square form of outer casing. The normal water level is shown by the chain dotted line. If this construction is combined with a tapered course in the rear barrel section, an ideal condition is attained, though given a cylindrical barrel of sufficient diameter equally good results are to be had, but there is naturally rather more weight in the boiler. The round top form of fire-box casing has been combined with a tapered rear barrel section, as in Figs. 4 and 5. This improves the water line, but the latter is more susceptible to alteration with the rise and fall of the water level in the boiler than is the case when the Belpaire or square-top fire-box is employed.

Two sections through the fire-box of an excellent example of a high-capacity boiler for a 4-6-0 type express engine designed by Mr. R. E. L. Maunsell, for the Southern Railway, are shown in Fig. 7. The long and narrow form of grate has an area of 33 sq. ft., and a special feature of the design is the large size of the fire-box and the manner in which it has been extended forward to obtain additional volume. This has rather restricted the length of the tubes, which are only 170 ins., with a diameter of 2 ins. Another good point in this particular design is the adequate distance of 24 ins. between the crown of the inside fire-box and the inside of the outer wrapper, thus ensuring a good steam space. Ample steam space, or volume, is very necessary as it is the only means whereby dry steam can be obtained, and this together with water-line area over the back half of the boiler are the principal factors. In conjunction, they govern very largely the superheat obtainable from a given superheater and rate of working. Boilers may often be improved by increasing steam space, and too much attention cannot be given to this, even to the extent of decreasing heating surfaces to obtain it.

The standard form of boiler employed for modern locomotives on the Great Western Railway includes the Belpaire fire-box construction in conjunction with the taper form of barrel, and these two feature increase the water-line area over the fore part of the fire-box. The back plate is sloped, thus giving more room in the cab, reducing weight, and helping the flames to pass over the rear sheet. Ample space between the inner fire-box roof and the outer casing is provided. These boilers have been most successful, and the adequate steam space and large water-line area, are factors which have, without doubt, been found of great benefit. No steam dome is provided, the steam being collected from the highest point above water level, by means of an internal pipe, extending back to the fire-box tube-plate.

A further example of boiler design is given in Fig. 8. This boiler is for the three-cylinder "Atlantic" type passenger engines in service on the North Eastern section of the L.N.E. Railway. The box is deep, and the grate area moderate, being 27 sq. ft. These boilers steam very well, and Fig. 9 gives the

results obtained in certain tests, and are based on data taken from a paper read by Mr. H. N. Gresley, C.B.E., before the Institution of Mechanical Engineers in 1925.

The proportioning of the grate area and heating surfaces, and the relation which these characteristics bear to the cylinder power vary within quite wide limits, according to the ideas of different designers. It is not intended to discuss this question exhaustively, but rather to indicate certain general principles.

Commencing with the size of the grate, which is of far-reaching importance, the first consideration is the maximum rate of firing, and the class of fuel to be used. In discussing this Mr. J. T. Anthony* suggests that the grate should be directly related to the cylinder H.P., and the coal, per H.P.-hour, and based on a firing rate of 120 lbs. per sq. ft. of grate area, per hour.

Calculating the maximum H.P. by the American Locomotive Company's method† thus :—H.P. $=.0229\times P.\times A.$; P=boiler pressure; A=area of one cylinder in square inches. Assuming $3\frac{1}{4}$ lbs. of coal per H.P.-hour. The grate area for 14.000 B.Th.U.'s coal is $\frac{\text{Cyl.: H.P.}\times 3.25}{120}$. The grate will be larger for coal of inferior quality if burned at the same rate, therefore, the grate area should be equal to $\frac{\text{Cyl.: H.P.}\times .37}{\text{1,000 B.Th.U.'s in coal}}$. Having decided the grate area, a dimension which is directly related to this figure, is the net gas area through the flues and tubes. Using 3.25 lbs. of coal per H.P. and assuming 10.35 lbs. of gas per lb. of coal, and taking as the weight of gas that can be passed through each sq. ft. of gas area 10,800 lbs. per hour, the net area is given by $\frac{\text{Cyl.: H.P.}\times 3.25\times 10.35}{10{,}800} = \frac{\text{Cyl.: H.P.}}{330}$. The coal consumption figure given is, probably, unduly conservative, and 2.75 lbs. is a better value to work on, as it gives for 1,000 H.P. a grate of 23 sq. ft., which conforms to British practice using coal of a value of 14,000 B.Th.U.'s.

The net gas areas calculated as above, and for grates obtained in the manner proposed, give areas equal to about 10 per cent. of the grate. British practice allows the rather larger percentage of about 15 to 17.

The size and volume of the fire-box are dimensions of importance, and especially for bituminous coal a large volume is desirable in proportion to the fuel fired. Generally when comparing different fire-boxes, it can be said that their relative volumes will vary as the ratio of proportion existing between the heating surface and the grate area. On the other hand it will not of necessity follow that the fire-box having the largest ratio will be the best, because the grate may be small for the power required. Mr. Lawford H. Fry, suggests that the grate area, divided into the rated tractive effort, may have the following values:—

Type.	Passenger engines.		Type.	Freight engines.	
4-6-2	Superheated	650	2-8-0	Superheated	925
	Saturated	550		Saturated	825

The ratio of proportion between the area of the grate and the fire-box heating surface, it is suggested, should be 4 to 4.5, these being minimum values.

The airways through the grate bars and ashpan comprise other particulars which require attention.

THE ENGINE.

Apart from the efficient generation of steam, an important controlling feature in the ultimate overall efficiency of the locomotive, is the utilisation of the steam in the cylinders, and the coal required, per horse-power developed, on the draw bar is not only influenced by the water evaporated, per unit weight of fuel fired, but also largely by the cylinder efficiency, the steam rate per I.H.P. hour, but also by the running resistance of the locomotive as a whole.

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*" Important Factors in Design of Locomotive Boilers," J. T. Anthony.
†" Locomotive Handbook." American Locomotive Co., 1917.

The tabulated statement following gives the leading particulars of a number of typical boilers, some of which are illustrated in this article, and a study of the proportions will show the views of eminent designers.

PRINCIPAL DIMENSIONS AND PROPORTIONS OF TYPICAL LOCOMOTIVE BOILERS.

Railway	L.N.E.R.	S.R.	G.W.R.	L.N.E.R.*	S.R.†
Engine Type	4-6-2	4-6-0	2-8-0	4-4-2	4-6-0
Working Steam Pressure Lbs. per sq. in.	180	220	225	180	200
Heating Surfaces, sq. ft.					
Tubes	2,715	1,795	2062.35	1299.3	1716.0
Fire-box	215	194	169.75	182.8	162.0
Total Evaporative	2,930	1,989	2232.10	1482.1	1878.0
Superheater	525	376	323.90	389.5	337.0
Combined	3,455	2,365	2256.00	1871.6	2215.0
Grate Area, sq. ft.	41.25	33.0	30.28	27.0	30.0
Fire-box—Grate Area	5.2	5.88	5.57	6.8	5.4
Fire-box—Combined H.S.	6.2	8.2	6.6	9.7	7.35
Superheater—Combined H.S.	18.2	15.9	12.6	20.7	15.2
Combined H.S.—Grate Area	84.0	71.7	84.0	69.4	73.8
Tubes diameter and length between tube plates	2¼in.— 19ft. 0in.	2in.— 14ft. 2in.	2in.— 15ft. 2½in.	2in.— 16ft. 2⅝in.	2in.— 14ft. 2in.
Length between tubes plates—Tube diameter—outside	102	85	94	97	85

The question of cut-off has an important bearing on the fuel consumption, per horse-power developed. The short cut-off takes less steam from the boiler, thus lowering the rate of evaporation and fuel consumption, and indirectly increasing the boiler efficiency. It must be stated, however, that this seems especially true for fast running engines, and cylinder capacity should be so proportioned that the short cut-offs will furnish the requisite horse-power, as dictated by the average service requirements. At lower speeds, short cut-offs are not so important.

Valves and Valve Gears. When any improvements to the engines are under review, the question of valves and driving gear presents itself. Piston type valves are commonly used, but they cannot be well arranged from the point of view of giving adequate exhaust passages, and at the shorter cut-offs the steam inlet is also much restricted. This can be overcome by increasing sizes, but this is objectionable.

Poppet type valves are greatly superior in both these respects, and offer certain other practical advantages; they require less power for their operation, and motion parts are, therefore, lighter. Any valve gear giving a reciprocative motion such as Walschaerts' or Stephenson's, is ill adapted for expansive working, if the highest economies are desired, for the reason that an early cut-off means also an early exhaust port opening, with accompanying high release pressure, followed by an early closing to exhaust, and high compression. Poppet type valves also possess the advantage of separated steam and exhaust valve events, and the general adoption of such valve gears is, no doubt, only a matter of time.

High-pressure Steam and the Compound Principle. The use of high-pressure steam as a means of promoting higher working economy is receiving much attention. In Great Britain, boiler pressures of 180 to 200 lbs. per sq. in. have been common for years past; some lines, notably the Great Western, have used higher working pressures, 225 lbs. being standard for all large main-line engines. Recently 250 lbs. has been introduced for some powerful passenger locomotives on the Great Western and L.M.S. Railways. Cylinder capacity has not greatly increased during the last three decades.

*Boiler, Figure 8; for Performance Characteristics, see Figure 9.
†Boiler for S.R. 4-6-0 Engine, used for Trials, made with Welsh and Yorkshire coal.

From the point of view of an increase in thermal efficiency any increase in steam pressure must be accompanied by an increase in the ratio of expansion, as if the terminal pressure is increased part of the economy obtainable may be lost.

Authorities give 250 lbs. per sq. in. as the maximum practical limit of boiler pressure for simple expansion locomotives. Such being the case, the subjects of high-pressure steam and the application of the compound system present themselves, and the writer is of the opinion that these two features, taken in conjunction with a modified fire-box construction for the boiler, offer an immediate solution to the problem of designing locomotives to meet the growing demands for higher power and increased efficiency. Subsequently, other obvious modifications may be made. A three-cylinder compound expansion locomotive built by the Baldwin Locomotive Works, in 1926, has shown steam rates per I.H.P. hour which averaged from 15 to rather less than 16 lbs. throughout a power range of from 1,500 to 4,500 I.H.P.

Compared with this, a high-speed passenger engine of admittedly excellent design, tested on the same plant, developed from 1,000 to 2,400 I.H.P. over steam consumption of 19 lbs. at the former to 18 lbs. at the latter output, with a maximum economy of 17 lbs. at between 1,800 and 2,000 I.H.P.* The compound works at 350 lbs. per sq. in., and the simple at 205. Both have the same type of superheater equipment, valves and motion.

Fuel economy points.

Beyond the influence of good design on fuel consumption, there are other factors which have an important bearing on this question, and attention may be drawn to the following considerations.

It has been pointed out that the practice on British railways is to use coal of good quality, usually fired in rather large lumps. Small coal of lower grade quality would necessitate much larger grates, and mean the general introduction of the wide fire-box, and, consequently, locomotives of a given capacity would have to be longer and heavier

There is, however, another method of utilising low-grade coal for railway locomotive service, which may be mentioned. The use of coal in the powdered form is now well known in stationary power plant practice. It has received consideration by locomotive engineers, though actually, little experimental work has, as yet, been done on the railways in this country. The subject of feed heating at terminals is worthy of attention. If it can be accomplished by using heat that would otherwise be wasted, large savings in the coal used for lighting are possible. Hot-water washing-out plants are now often employed. By their use, it is possible to refill the boiler with hot water, and then, if the engine is going out reasonably soon after washing out, much coal is saved in raising steam.

However, perfect locomotive design may be and however well they may be kept in repair, the best performance, from the point of view of power output and the fuel rate per unit of power delivered, constituting the practical results on the road, are entirely in the hands of the enginemen. The success attained with modern equipment turns on its intelligent use.

Instruction to enginemen in the proper operation of locomotives is therefore another point to be emphasised when economic working is most desirable.

In everyday practice, the writer is aware of the difficulties which beset those who favour and appreciate this truth, but every effort should be made to get the men on the footplate to learn the fundamentals which govern the action of the boiler, and the engines. It is thought that more might be done in this respect, especially when it is considered that of the number of railway men of all grades employed, totalling 671,500, but 25,000 attend classes of instruction in any subject.

In reviewing in a general manner, the action of the locomotive, and the coal consumed for the work done, and those factors which govern economic performance, certain fundamentals are brought into prominence, which, in turn, prompt proposals for effective improvement. In conclusion, these suggestions are offered:—

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*Pennsylvania Railway Test Plant Bulletin No. 27. "Tests of A Class E.G.S. Locomotive."

(1) In the design of boilers, steam space, and water volume at the fire-box with an ample water-line area, are absolutely essential.
(2) Superheater efficiency depends on the dryness of the steam supplied, very ample steam space is therefore of prime importance, even to the extent of a slight loss in possible heating surface.
(3) A large grate is required, this helps materially to reduce mechanical losses in the fire-box, *i.e.*, cinder loss, and assists the chemical actions of the combustion process.
(4) Attention to airways, the damper, grate openings, and the net area through tubes. Large airways mean greater steaming capacity and a lower draught, with, in consequence, less back pressure on the pistons.
(5) Hot-feed for the boiler, properly used. Feed systems fail principally through being improperly handled.
(6) Good firing with knowledge gained by expert instruction. Coal consumptions should be recorded, and compared, and performance therefore held constantly under supervision.
(7) Engines should be run with full steam on, *i.e.*, regulator wide open, the power developed being regulated by the reversing gear, and the steam thereby used expansively. Passenger engines should normally operate at cut-offs not exceeding 25 to 30 per cent.
(8) Goods engines should have a maximum full gear cut-off of not more than 60 per cent.
(9) Engines employed in shunting operations should have a maximum full gear cut-off of 60 per cent., or even 50 per cent. This system would save at least 25 per cent. in the fuel used and possibly much more.
(10) Locomotive runs should be extended as much as possible, thus reducing stand-by losses, and increasing the value of the locomotive hour.

Railway locomotives of the normal types, can be so designed that a fair economy in coal, based on the work done, is obtainable. As non-condensing engines excellent steam consumptions are possible, if attention is given to the main essentials, but much more can, and will, be accomplished in the near future. With high steam pressures, and the application of the compound principle in conjunction with high-temperature superheating, it may be confidently anticipated that steam consumption on the drawbar-H.P. basis will be obtained, at least equal to those now realised for cylinder H.P., which are so excellent as to be exceptional, surely a great and far reaching advance.

The illustrations of the various boilers given are, with the exception of Figs. 4 and 5, adapted from those appearing in a contribution on the subject of Locomotive Boilers by Sir Henry Fowler, K.B.E., and S. J. Symes. The boiler drawings, Figs. 4 and 5, are reproduced, by permission of Mr. H. N. Gresley, C.B.E., Chief Mechanical Engineer, L.N.E.R.

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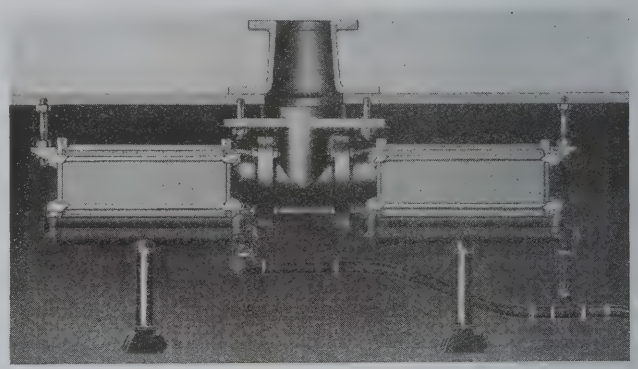
Chapter 8.

BOILER PLANT AUXILIARIES.

(1) SUPERHEATERS AND SUPERHEATED STEAM.

Steam Generation. As a preliminary to the consideration of superheating, it is advisable to examine the conditions under which steam is generated. This is usually carried out in boilers where the vapour is produced in intimate contact with the water, and as evaporation is accompanied by violent agitation due to liberation of steam bubbles at the water surface, small particles or films of water become mixed and entrained with the vapour, and the steam is therefore in a wet and supersaturated condition if it is delivered direct from the boiler to the steam main.

The amount of entrained water will depend upon the specific density or pressure at which the steam is generated, also upon the purity and general characteristics of the water and in a very large measure upon the design of the boiler. High pressures tend to a low water content, as the volume of the generated steam is less than at low pressures, and the surface disturbance during evaporation is correspondingly decreased. Water containing floculent solids in suspension, or salts which tend to precipitate, is usually a very active agent in producing wet steam, and should the concentration of the salts be accompanied by foaming, this will result in large quantities of water, together with suspended matter, being carried away with the steam. This condition, which is generally known as boiler priming, constitutes a serious menace to the safety of the steam mains and power plant, and is also productive of heavy wear and tear. All feed water softening plant should be adequately supplemented by filters which remove the whole of the precipitation, and regular blowing down of the boilers should be carried out to prevent any undue concentration of original salts, or the soluble constituents produced during the softening process.



Tracey Separator and Purifier.

Boilers should always be provided with division plates, and special separating apparatus for reducing the amount of the water carried over with the steam. The separator illustrated in Fig. 1 promotes mechanical separation of the entrained particles and is of great value in reducing the water content, particularly in cases where heavy priming is taking place. It is, however, impossible to completely eliminate the moisture by separating apparatus, and the only method of ensuring steam in a perfectly gaseous condition is by the application of superheat.

Thermal Properties of Saturated and Superheated Steam. The heat content, specific volume, and temperature of steam at various pressures were carefully investigated by Regnault some eighty years ago, and the classic formula $H=1091.7+0.305\ (t-32)$ was evolved for the total heat in dry saturated steam, that is steam which is at the temperature of generation and is entirely free from unevaporated particles. Recent investigations show that Regnault's formula requires slight corrections for temperatures which are much higher or lower than 212° F., and reference should be made to a modern set of steam tables for all data required in connection with supersaturated or superheated steam.

When using these tables, corrections should always be made for wetness, as the dry saturated condition for which the tables are calculated is never attained except in the physical laboratory, all steam

used as a medium for power generation being either superheated, or supersaturated. Unfortunately, the measurement of the moisture content of steam, as it leaves the boiler or during its transmission in the pipe-lines presents considerable difficulty, and as a result corrections for steam quality are very often neglected in boiler evaporation and efficiency tests.

Fig. 2 gives a number of curves for heat content of steam at pressures from zero to 500 lbs. per square inch, and for various qualities of steam. All pressures are marked to coincide with ordinary boiler gauge readings under an atmospheric pressure of 29.9 inches, and the heat units have been set out from a zero of 100° F., as this is more convenient than the usual zero of 32° F. and also approximates closer to the lower limits of condenser and feed temperatures. Curves are given for dry saturated steam in agreement with the recognised steam tables, also for superheats of 100°, 200°, and 300° F., and for a moisture content of 5 per cent. Examination of the two lower curves will show that an error of 3-4 per cent. is introduced in calculated boiler efficiency, by assuming that steam containing 5 per cent. moisture carries the same heat content as dry saturated steam.

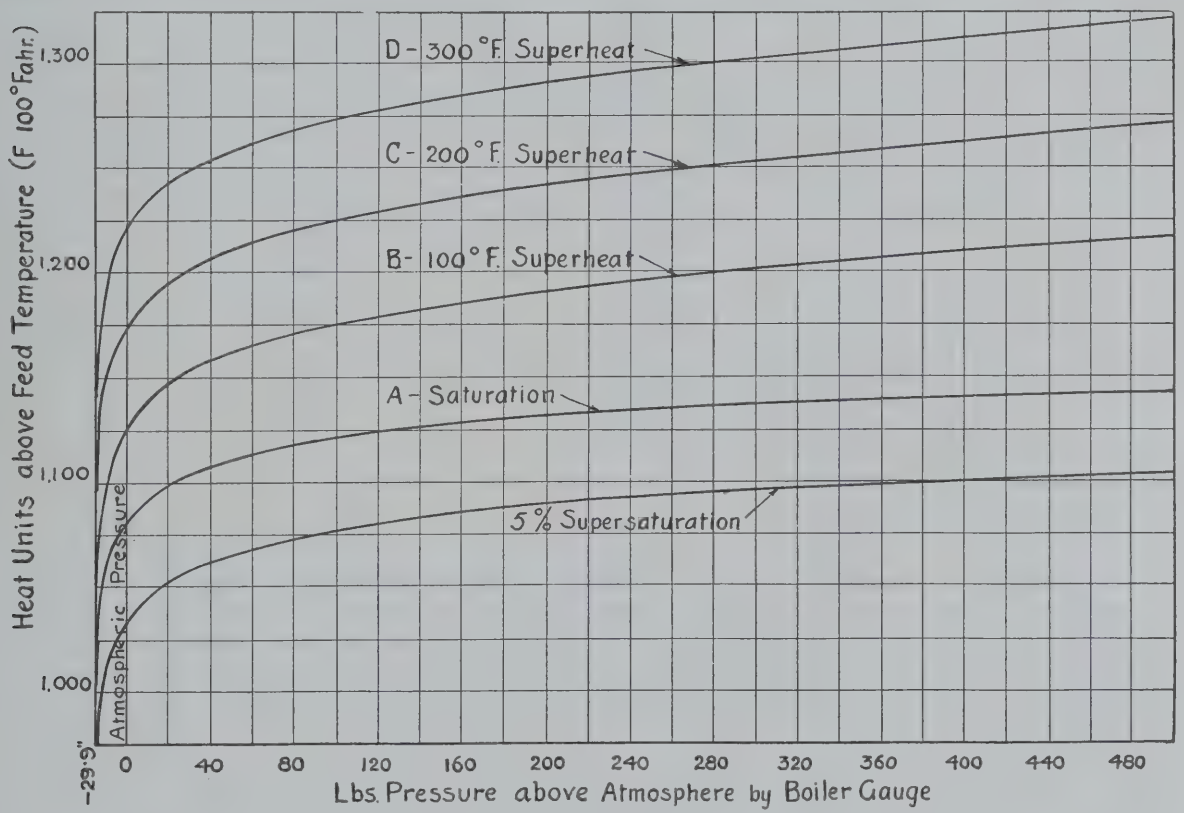


Fig. 2.

The process of superheating consists of the addition of heat after the steam has left the boiler, whereby all moisture carried over from the boiler is evaporated and the steam is brought into a perfectly gaseous condition, and is raised to a temperature higher than that at which it enters the gaseous condition. Superheating is usually carried out at a constant pressure equal to that at which the steam is generated, and is accompanied by an increase in volume simultaneously with the rise in temperature. The volumetric increase varies slightly with temperature and pressure, but is approximately 1 per cent. for the first 25° F. rise above saturation temperature, and a further increase of 1 per cent. for each succeeding 30° F. temperature rise. The quantity of heat required for each 1° F. rise in temperature, varies between wide limits. Fig. 3 shows the variation of the specific heat at constant pressure between saturation temperature and 900° F. The curves which are based on Regnault's and Knoblauch's experiments show that the

specific heat of high-pressure steam is greater than unity near saturation temperatures, but approaches 0.5 for high superheats. The formulae for calculation of exact heat content and volume are somewhat complicated and reference should be made to a set of steam tables for exact values, when these are required for calculations of efficiencies, etc.

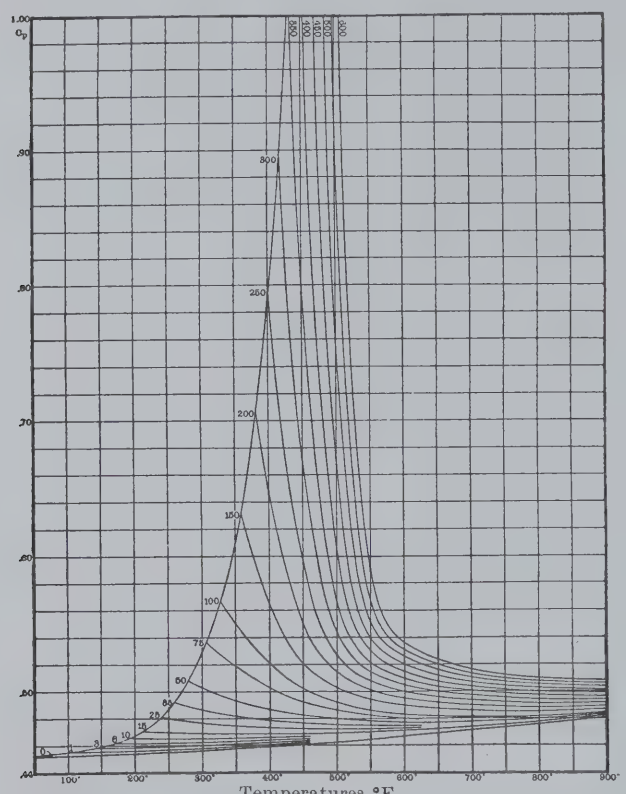


FIG. 3.—*Steam Pressure Curves showing Variations of Specific Heat during Superheating.*

Economic Advantages of Superheat. The economic advantages of superheating for power generation are due principally to differences in the physical properties of steam, when in a perfectly gaseous condition compared with steam which is wet and supersaturated. The purely thermodynamic basis takes no account of the physical condition of the medium, and thus the possible maximum efficiency by the Rankine cycle for steam of 165 lbs. absolute pressure, superheated 250° F. and expanded adiabatically in a steam turbine or reciprocating engine to a back pressure of 2 lbs. absolute, is only 5 per cent. greater than for steam at the same pressure containing 5 per cent. moisture. In actual results the superheated steam will show an increased efficiency of 20 to 30 per cent., and, therefore, comparative analysis of the advantages of superheat must take the physical conditions into account.

Superheat for Engines. With reciprocating engines the economy secured by superheat is principally due to reduction of cylinder condensation losses. In all such engines the conversion of heat into work is effected by a cycle of pressure changes in the cylinders, and as the pressure changes are accompanied by variations in temperature of the steam, corresponding variations of temperature are imparted to the inside of the cylinder and other parts which are in intimate contact with the working medium. In the case of a single-cylinder condensing engine supplied with steam at 150 lbs. pressure, such steam if saturated will have a temperature of 366° F., and on its admission to the cylinder will attempt to heat the whole of the metal with which it is in contact to 366° F. During this operation heat will be abstracted from the steam, condensation will follow, and water will be deposited as a film on the cylinder walls and other metal surfaces which have abstracted heat from the steam. The admission period is followed by expansion of the steam, and the temperature and pressure will be lowered, and should the steam temperature fall below the temperature of the walls re-evaporation will commence. On the completion of the expansion period the cylinder is put into free communication with the condenser which may have a temperature of about 120° F.; the greater part of the steam will then enter the condenser, and the steam remaining in the cylinder will be brought to pressure and temperature conditions approaching those of the condenser. Complete re-evaporation of the whole of the water film will take place simultaneously with the change of conditions in the cylinder and heat will be abstracted from the cylinder walls, etc., which will be brought thereby into an active condition for condensing the incoming steam during the next cycle. The amount of steam lost by condensation will depend upon the difference in temperature of the admission steam and that of the condenser, also upon the area of metal surfaces which are exposed to the temperature changes, and the length of time between the temperature changes; radiation and conduction will also affect the condensation in a minor way.

The drop in temperature which occurs during the exhaust period is the primary source of cylinder condensation, and in engines which are supplied with wet steam may account for more than 50 per cent. of the total steam used by the engine. Practically the whole of this condensation re-evaporates and passes to the condenser without contributing any pressure effect upon the piston, and is therefore a very inefficient feature in the operation of reciprocating engines. The conversion of heat into work is productive of condensation independently of the changes of temperature. This condensation does not represent any loss of efficiency, but the presence of the condensate increases the rate of absorption and rejection of heat by the internal surfaces.

Many attempts have been made to reduce the losses by cylinder condensation, and the greatest success has been attained by the use of superheated steam in conjunction with compound cylinders, high cyclic speed, and the reduction to minimum area of all internal surfaces which are affected by temperature fluctuations of the working steam.

The adoption of compounded engines in which the expansion of steam takes place in two or more stages enables the temperature drop for any individual cylinder to be reduced in proportion to the number of cylinders in series, and has proved very effective in increasing the efficiency of engines using saturated or superheated steam (see Table A, page 174). An increase in cyclic speed reduces the time period during which the internal surfaces extract heat from the steam or discharge heat into the condenser during each cycle, and thereby reduces the condensation; this is also effected by reducing the area of the internal surfaces to minimum value and making such surfaces as smooth as possible. The increase in cyclic speed also reduces conduction and radiation losses per unit of power.

Superheated steam owing to its dry gaseous condition has a much lower heat conductivity than steam containing moisture, and thereby reduces the rate of absorption and rejection of heat by the internal surfaces. Superheated steam also carries a heat reserve which is available for conversion into work or imparting heat to the internal surfaces without condensation; thus steam of 150 lbs. pressure superheated 300° F. can give out 156 heat units (see Fig. 2) and retain the gaseous condition.

Other attempts to reduce condensation include the provision of steam-heated jackets surrounding the working cylinder, also addition of heat to working steam during its transfer from one cylinder to the next one in the series. The use of steam-heated cylinder jackets introduces considerable complications in the engine, and whilst there is a reduction of internal condensation due to the heat transferred from the jacket steam, this involves a new wastage by condensation of the steam inside the jacket space. The provision of heat reserve in the working steam by superheating is a more direct method of supplying the working steam with extra heat, and whilst steam jackets secure some increase of efficiency in non-superheated engines, no advantage can be shown where the steam is supplied in a superheated condition. The process of reheating the steam between the cylinders is, however, an advantage for slow-speed engines using superheated steam.

The actual effect of superheat in the cylinders of reciprocating engines is the raising of the surface temperature to a higher level and the maintenance of the surfaces in a much drier condition, by which transfer of heat to and from the steam is greatly reduced.

The development of one horse-power hour involves the conversion of 2,556 units of heat into work, and in the case of an engine using 10 lbs. of steam per horse-power-hour such conversion represents 255.6 units per pound of steam. The total work which has to be done by the steam is considerably in excess of the horse-power rating, and includes the work necessary for expelling the steam from the cylinder against the back pressure of the condenser or of the atmosphere in non-condensing engines. The horse-power is represented by the difference in mean pressures on the steam and exhaust sides of the piston, but the actual work done by the steam is represented by the mean pressure on the steam side without any deductions. In a single cylinder engine the ratio of the mean back pressure to the total mean pressure on the steam side will be about 4 to 30, and as the difference of 26 represents the horse-power the total heat equivalent per lb. of steam will be $255.6 \times (1+\frac{4}{30}) = 289.7$ heat units per lb. steam. A considerable

percentage of the work done in the cylinder takes place during admission of the steam before expansion has commenced, and such work is actually part of the work done by the boiler and superheaters and is not accompanied by any heat drop or fall of temperature. This work is represented by heat units in the expression $H = \frac{144\ pv}{778}$ where p equals the absolute pressure of the steam in lbs. per square inch, v represents the volume of steam at the given pressure and temperature, and H equals the external energy of evaporation at constant pressure. H for saturated steam of 165 lbs. absolute pressure =83.7, and 117.2 for steam at 165 lbs. pressure superheated 250° F. If the engine is therefore supplied with steam at a boiler pressure of 150 lbs. superheated 250°, the heat converted into work during expansion will be 289.7—117.2=172.5 units, which is equivalent to the heat reserves obtained by superheating the steam about 320° F. In compound and triple-expansion engines a considerable amount of the expansion takes place in the receivers and thereby reduces the total heat drop, as this is confined to work done by successive expansion in the cylinders. To prevent condensation during expansion by conversion of heat into work, 300° F. superheat is necessary in the case of single-cylinder uniflow engines using 11 lbs. of steam per horse-power, and about 250° F. for triple-expansion engines using 10 lbs. of steam per horse-power. Fig. 4 shows the actual savings in steam consumption which have been obtained under test for a high-speed triple-expansion engine supplied with steam at 160 lbs. pressure and for superheats from dry steam to 350° F. The saving at full load by 300° F. superheat is 34.2 per cent. in weight of steam used and about 25 per cent. in heat units.

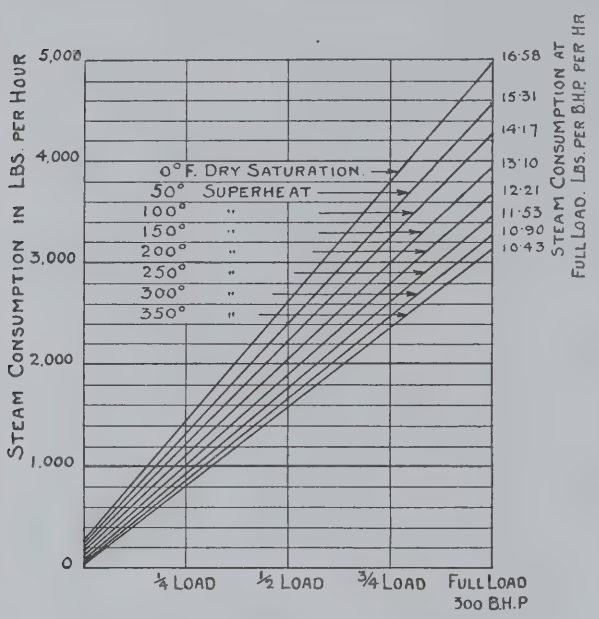


Fig. 4.—*Willan's straight-line Curves for total steam consumption for high-speed* 300 *B.H.P. Triple Expansion Engine.*
Note—The saturated steam line is for steam slightly superheated to ensure dryness.

The steam consumption for various types of engines specially designed for economy and the savings obtained by superheating are shown by Table A.

Table A.—Steam Consumption per B.H.P. per Hour for Various Engines.

Type of engine.	No superheat. 160 lbs. pressure.	200° F. superheat. 160 lbs. pressure.	Saving in steam by superheat.
Single-cylinder, non-condensing	25	20	20%
Uniflow, non-condensing	20	17.5	12.5%
Compound, condensing	14	10.5	25%
Uniflow, condensing	13.8	10.8	23%
Compound high-speed, condensing	16	12.8	20%
	No superheat. 200 lbs. pressure.	200° F. superheat. 200 lbs. pressure.	
Triple-expansion, condensing	12.5	9.7	23%
Triple-expansion, high-speed, condensing	14.2	11	22%

The comparison in Table A. is between absolutely dry steam and superheated steam, and where moist steam is used the figures in column 2 and 4 will be considerably increased.

The single-cylinder uniflow engine owes its economy in a large measure to the short period during which the cylinder is in direct communication with the condenser, also to the arrangement of the valves and piston by which the flow of steam is directional from the admission end of the cylinder to the condenser, thereby reducing the temperature drop at any special point in the cylinder.

Steam Turbines. The conversion of heat into work by a steam turbine is principally effected by utilisation of the kinetic energy of steam moving at a high velocity, and the advantage of superheat is in the low frictional resistance of dry steam as compared with steam containing moisture. Turbines are usually provided with nozzles arranged to give high velocity by the adiabatic expansion of high-pressure steam to a lower pressure, and the velocity and kinetic energy attained by the steam during expansion is accompanied by reduction of the heat content of the steam in accordance with the general formulae for kinetic energy, thus:—

$$H=\frac{\text{Ft.-lbs. energy}}{778}=V^2\times .01562.$$

where H= British thermal units converted into kinetic energy per lb. of steam and where 1 B.Th.U. =778 foot-lbs.

V =Velocity of steam in feet per second.

By the above formulae a velocity of 2,000 feet per second will involve a heat exchange of 80 B.T.U. and with an initial steam pressure of 180 lbs. absolute, the fall during expansion would be from 180 lbs. to 65 lbs. absolute, and with an assumed 2 per cent. wetness in the initial steam the expanded steam would contain $8\frac{1}{2}$ per cent. moisture. The wetness in the steam would reduce the initial efficiency on account of the relatively high frictional resistance of the steam during its passage through the nozzles and the fixed and moving vanes, and a further progressive reduction in efficiency would take place by erosion of the turbine blades, which are particularly liable to lose their original contour where wet steam is used for driving the turbine.

By superheating steam of 180 lbs. pressure 200° F. a velocity of 2,000 feet will be attained by expansion to 80 lbs. pressure, and the expanded steam will carry 80° superheat and can be further expanded to 42 lbs. absolute pressure before any condensation will take place. The advantage of dry steam in preventing erosiou is of the greatest importance in maintaining the efficiency at the initial standard and in reducing costs for maintenance, and in order to extend this advantage modern turbines of large capacity are arranged so that the steam can be re-superheated after passing through the high-pressure section of the turbine, and the steam can then be expanded to a fairly low pressure before any condensation will take place.

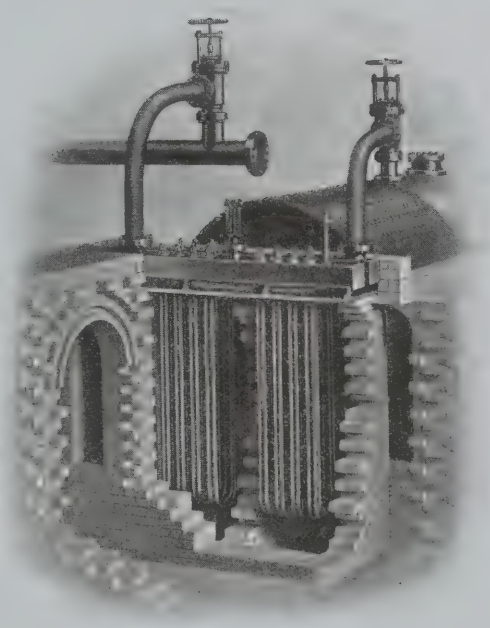


Fig. 5.

The economy secured by superheat is generally found to be about 10 per cent. for 100° F., 18 per cent. for 200°, and 25 per cent. for 300°, and the foregoing particulars of test show the reduction of superheat and condensation of steam passing through a 10-stage turbine.

	Initial steam.	Stages.									
	0	1	2	3	4	5	6	7	8	9	10
Abs. pressures.	265	120	68	48	28	16	9	4.7	2.4	1.1	.5
Superheat.	250	160	120	75	30						
Moisture.	0%	0%	0%	0%	0%	.6%	2%	4%	6.5%	8%	10%

Locomotives. Superheating has been found of great value for locomotives. These engines are subject to extreme variations of load and generally work at high piston speeds. The higher mobility of superheated steam reduces the loss of pressure between the boiler and cylinder, and also reduces the resistance of the exhaust steam. Both these factors are generally high in locomotive engines, and there is considerable increase in efficiency by reduction of these losses, which are superposed on the usual cylinder condensation losses of reciprocating engines.

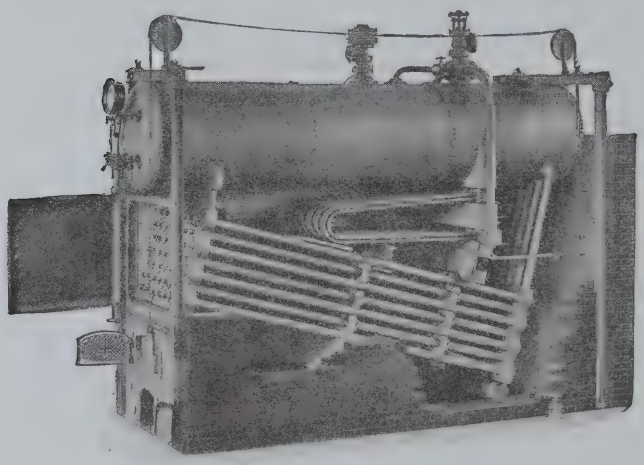


Fig. 6.

Transmission and general use of superheated steam.

The gaseous condition of superheated steam and its relatively low frictional coefficient enables the steam to be transmitted at much higher velocities than are permissible with wet steam, whilst the loss of pressure during transmission is practically one-half of that for wet steam moving at the same velocity. For steam pipes of 3ins. to 9ins. diameter saturated steam can be satisfactorily transmitted at 80 to 90 feet per second, but if the steam is perfectly gaseous the speed may be from 120 to 130 feet per second, and for pipes over 9ins. diameter speeds up to 150 feet per second may be adopted. This permits reduction in size of pipe-lines with saving in first cost and in the radiation losses. Steam trap and drainage losses are also eliminated.

Superheated steam is generally advantageous for boiling and general process work, and the possibility of distribution over wide areas without condensation is of great value in many cases. The pipes used for transmission of superheated steam should be of minimum diameter for the amount to be transmitted, and should be well covered with non-conducting composition so that the radiation is kept as low as possible.

Superheated steam can exist in the presence of water, and in cases where large pipes are used and the steam is flowing at a low velocity it is quite possible to deliver superheated steam through an upward branch and to drain off water from the bottom of the pipe through which the superheated steam is being conveyed.

Design and construction of superheaters.

Wrought steel is exclusively adopted for the construction of superheaters, and the fittings require to be made from metals which are not oxidised or reduced in strength by high temperatures. Tubular elements are used for transmitting the heat to the steam, the tubes being usually of small diameter, say, 1¼ins. to 1¾ins., the object being to break up the steam into a large number of streams, each of which will be brought into intimate contact with the inner surface of the tube and will be uniformly heated by the eddying effect of the tube wall upon the several particles of the stream of steam. The elements should be placed in the flues, where they will be exposed to external contact of gases at temperatures between 1,000° F. and 1,600° F., and should be arranged so that an active current of hot gas is passing over the whole of the elements. Superheating can be successfully carried out with gases below 1,000° F., but this involves very large heating surfaces; higher temperatures than 1,600° F. can also be used, but there will be excessive wear and tear of the elements, and special precaution will be necessary for ensuring an active current of steam through all parts of the superheater elements whenever they are exposed to high-temperature gases. Alternative arrangement for flooding the elements with water are adopted in some types of superheaters to give protection during the period when steam is being raised or whenever the active current of steam is in any way interfered with.

The amount of heat transmitted per square foot of heating surface is largely dependent upon the temperature of the hot gases, and is not directly proportionate to the difference between the mean temperatures of the steam and the gases. With a gas temperature of 1,200° F. about 3,600 heat units per square foot per hour can be transmitted to steam of 180 lbs. pressure at a mean temperature of 480° F., that is during the process of superheating the steam from its saturation temperature of 380° F. to 580° F. This corresponds to a transmission of 5 heat units per square foot per hour per degree difference in the temperatures of gas and steam, and with a gas temperature of 1,200° F. and steam of any ordinary pressure and temperature, this rate of transmission applies generally to steam of any other pressure and temperature; that is a difference of 800° F. would give a transmission of 4,000 heat units. Variations in the gas temperature affect the rate of transmission independently of the difference between temperature of gas

FIG. 7.—*Foster Radiant Superheater.*

and steam, and the rate of transmission for gas of 1,600° F. is about 6.6 heat units per degree difference in temperature. An allowance for moisture should be made when calculating the heating surface, such allowance depending upon the conditions of steam generation and type of boiler.

Superheaters for Lancashire and Cornish boilers are generally fitted at the back end of the boiler seatings with the superheating elements exposed to the hot gases which pass through the downtake. These gases are usually at a temperature between 1,000° F. and 1,400° F, and are therefore very suitable for superheating; the superheater is also in a satisfactory working position and fits in with the general design of these boilers. Fig. 5 illustrates Messrs. T. Sugden's downtake superheater, which consists of a pair of wrought steel headers connected by loop tubes which are exposed to the hot gases and form the superheating elements. The loop tubes are secured to the headers by expanding the ends into holes formed in the bottom surface of the headers, and are arranged in groups of four tubes with hand-hole covers over each group of tubes. Provision is also made for examination of the superheater tubes and downtake, whilst the plant is in commission. Steam can be superheated up to 700° F. without difficulty, and

there is no necessity for flooding the superheater as condensation collects in the tubes during closing-down periods and protects the superheater tubes whilst steam is being raised. The pipe connections between the superheater and boiler are generally arranged so that the superheater can be isolated by stop valves, but such isolation should not be used except in emergency and for very short periods. Special arrangements for isolation can be made by placing the superheater in a two-chamber downtake fitted with dampers and by-pass flue. This permits the superheater to be isolated for long periods without damage and enables the temperature of the steam to be regulated as desired, by partly shutting down the dampers.

Fig. 6 shows the usual type of superheater for Babcock boilers. This superheater is constructed with wrought steel headers and double loop tubes on similar lines to the superheater already described and is typical of the application of superheaters to the tubular type of boiler, the heating elements being placed so that they are in contact with the gases which have made one pass through the boiler tubes. In the Stirling and other forms of cross-drum boiler the superheater tubes are placed immediately behind the first bank of tubes and hang in a position slightly inclined from the vertical.

Radiant Heat Superheaters (Fig. 7). These superheaters are specially arranged for powdered fuel installations, and are placed in the combustion chamber so that they are not traversed by the hot gases but are solely exposed to radiant heat, and the tubes are provided with fins to increase the amount of surface exposed to radiation and to protect the body of the tube.

(2) THE ECONOMISER.

By M. G. Wallace, B.Sc. (Eng.), A.M.I.E.E.

In the sequence of plant operations for the economical generation of steam, the economiser is designed and installed to reduce to a minimum the loss which occurs in the waste flue gases. It should be arranged so that the maximum heat transfer will be effected in the lower cycle of steam raising, thereby reflecting on reduced boiler heating surface, increased fuel economy and greater thermal capacity.

Types. There are several types at present in use:—(1) The cast-iron type with horizontal or vertical tubes; (2) the horizontal steel tube of large diameter (4ins.); (3) the bent steel-tube type; (4) the horizontal steel-tube type of 2ins. diameter; (5) the high-velocity type having steel tubes of $1\frac{1}{2}$ins. diameter.

(1) The standard vertical type consists of cast-iron tubes 4ins. in external diameter and of lengths varying from 9ft. to 13ft., made up in sections of 4, 6, 8 or 10 ft. tubes in width. These sections are erected in parallel and are connected at the top by plain branch pipes, and at the bottom by access branch pipes

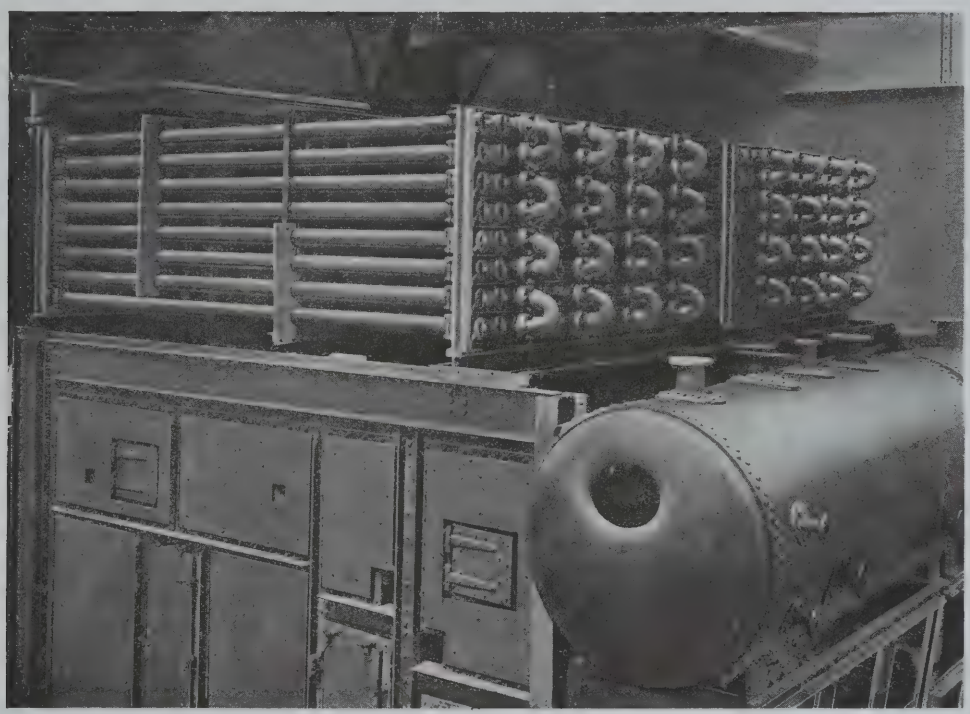


Fig. 1.—*Tri-tube Horizontal Economisers over a Water-tube Boiler.*

running lengthwise on opposite sides. The water to be heated enters at the bottom and rises; the waste gases travel in a horizontal plane. The exteriors of the tubes are kept clear of soot by mechanical scrapers moving up and down the tubes. The soot is deposited into a pit underneath for removal. To meet the modern boiler pressures above 250 lbs. per sq. in., a special type has been evolved, in which the tube joints (previously made by forcing the tube and socket together hydraulically) are reinforced. The reinforcement consists of an external ringplate and split ring threaded on to the end of the tube, the whole being held together by four set screws. These joints have been tested satisfactorily with a load of over 20 tons. The horizontal economiser is the result of the advent of the high-duty self-contained combined steam-raising unit, where restricted head room necessitated a horizontal economiser. The tri-tube economiser (Fig. 1) illustrates the cast-iron type used as a standard under the above conditions of high

duty and pressure. Each section consists of three tubes only, supported on vertical frames with ample provision for expansion. The water circulation can be arranged for either the series or parallel flow. The cold water enters at the bottom in this case also, a correct condition for this type of economiser. During

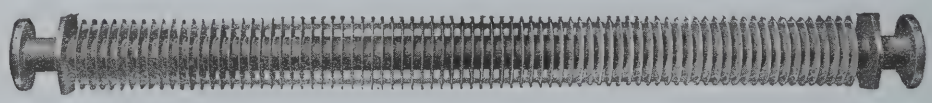


FIG. 2.—*Tube with Transverse Gills of large diameter.*

the last few years the progress made in respect to efficiency by increasing the gas velocities has resulted in the designing of the tubes to include gills (Fig. 2) so as to increase the heat transfer.

(2) The horizontal steel-tube type consists of tubes of 4ins. in diameter expanded into steel headers, which are arranged vertically and connected at their extremities into horizontal headers, by means of short steel nipples expanded in each component. A development of this type (Fig. 3) for higher efficiencies is that in which the tubes are expanded into horizontal headers and the flow of water is directed in the opposite direction to the flow of gas (contraflow). The water rises while the gas is directed downwards through the spaces between the tubes. A high heat transfer is obtained, the normal rating being in the region of 5 B.Th.U.'s per sq. ft. per hour, per deg. F. temperature difference. The thinness of the steel-tube economiser permits the heat transfer to be at the maximum and at the same time allows the economiser to respond quickly to any variation of loading on the boiler.

(3) The bent steel-tube type consists of tubes of $3\frac{1}{4}$ins. diameter expanded into large steel drums. The arrangement of the tubes is nearly vertical, with either one or two drums at the top, according to the requirements of the plant capacity. In this design, in addition to the high heat transfer, due to the fact that from its design it is easy to install the water and gas baffles, an extended contraflow principle

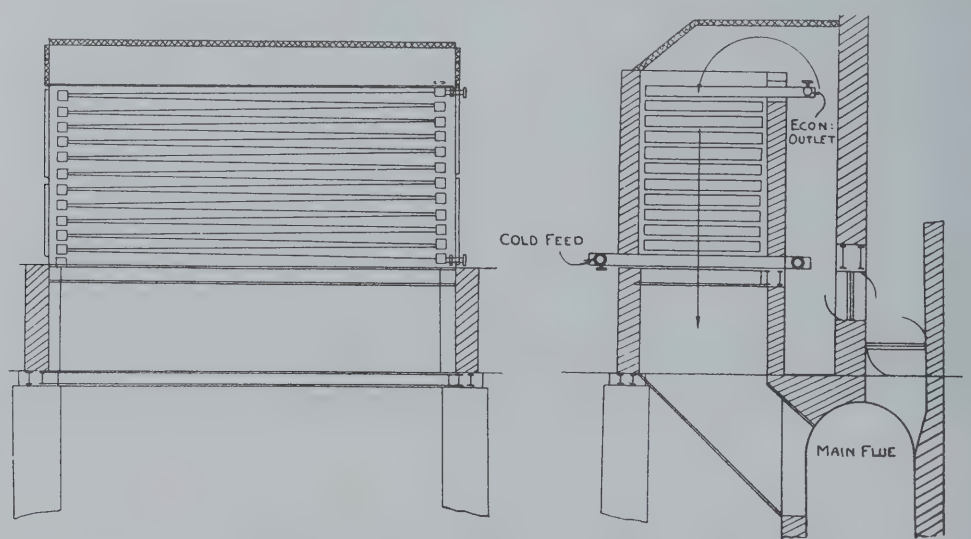


FIG. 3.—*Steel-tube Contraflow Economiser.*

can be established (taking into account the soot-cleaning object). The question of expansion troubles does not arise, owing to all expansions being taking up in the bent sections (Fig. 4). Internal cleaning operations are reduced, owing to the fact that only two or three drum-lid joints have to be broken and re-made, with consequent less chance of leakage. The large lower drum forms a convenient receptacle for sediment, which can be collected and blown out without the possibility of it entering the system. This type commends itself for robustness, flexibility and reduction of floor space, as it forms an integral part of the boiler.

(4) The horizontal-tube type of small tube diameter (Fig. 5) was evolved to meet the call for a very high-duty unit with maximum efficiency. It consists of straight, steel tubes of 2ins. diameter, expanded into cast-steel headers and fitted with cast-iron gilled tubes (Fig. 6), which are made a tight fit on the tubes and threaded over them the entire length exposed to the gas flow. Cast iron was chosen for this purpose, owing to its ability to resist the corrosive action of the flue gases. The extended surface having a greater outside area per unit of length than a bare tube, requires the minimum of space and permits of a less bulky construction. These economisers are all built on the contraflow principle and very high ratings have been established, reaching 8 B.Th.U.'s/sq. ft./hr./deg. F. The draught loss is higher than in the previous economisers, but the extra work necessary for this is said to be more than compensated for by the higher efficiencies obtained.

(5) The high-velocity (Fig. 7) type has tubes of about 1½ins. diameter expanded into circular headers of 8ins. internal diameter. The headers are set vertical with the tubes nearly horizontal, the rise being approximately 2ins. in a tube length of 60ft. The headers are set 3 feet apart, while the tube makes three double loops in connecting them together, the length of the economiser being about 10 feet from header to the top of the loop. The theory underlying this design was that, at a certain velocity of the water, the air entrapped in it is carried through by the turbulence caused, and not allowed to settle on tube walls and be the cause of the corrosion difficulties encountered. Above and below this velocity the bubbles cling to the tubes, in the first case by a banking-up effect caused through the high resistance and in the latter case by the velocity not being high enough. The pressure-drop on the water side is high; in the case under investigation it is in the neighbourhood of 20 lbs. per sq. inch. The gas velocities in this type have also to be high, in order to keep the tubes fairly clean. Contraflow is followed in this design and some very good results have been obtained.

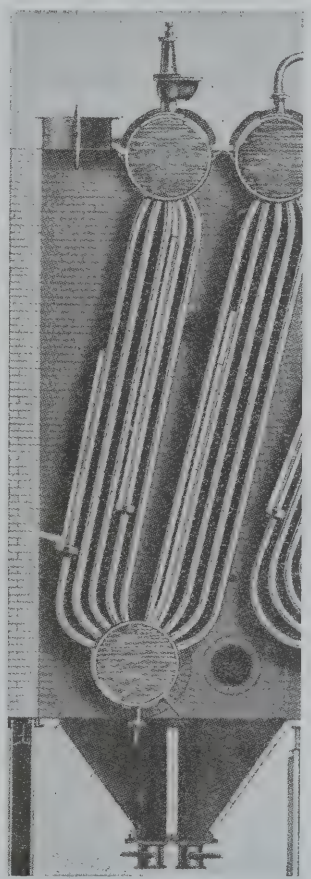


FIG. 4.—*Stirling Economiser.*

Design.

The modern tendency for intensive evaporations has modified design considerably. Previously it was the practice to take a standard boiler and design an economiser to reduce the exit flue-gas temperature to the lowest limit. The present-day practice is to consider the various sections of a steam-raising plant as a whole, and so design the separate parts that the most effective heat transfer can be obtained by eliminating that part of the boiler where the temperature differences between the water and gas are so low that considerable surface would be needed, and substituting an economiser section, where the mean temperature differences are much greater and the heat transfer much higher in consequence. No standard formula is applicable, as every case must be investigated by itself, in respect to fuel to be used, conditions of load, amount of hot water required if used for process work, and the possible installation of an air heater. An economiser designed on too generous lines may generate steam on peak loads. Another factor in the design of an economiser is that in modern central-station practice there is sometimes an advantage in preheating the feed-water by steam bled from the turbines, it being found that, in some instances, an increase of 11 deg. F. in the temperature of the feed-water entering the economiser leads to an increase of efficiency of approximately 1 per cent. Hence, the best economiser is one capable of cooling the gases sufficiently for the next apparatus in the series to be able to give the maximum efficiency, even though fed with water at 200 deg. F., and capable of raising the water to the highest possible temperature, which, however, should not be higher than 30 degrees F. below the boiler-water temperature.

Gas velocity.

The efficiency of an economiser depends to a great extent upon the gas velocity, which should be as high as possible, with due regard to the induced draught conditions, as this tends to prevent the deposition of soot and also to disturb the film of cold air which is present round the tubes and prevents the highest heat transfer. The general feeling that an increase in the water velocity is accompanied by an increase of heat transfer in an economiser, is open to doubt, because the heat transfer from tube to water is so much higher than from gas to the tube, that even a considerable increase in the former rate of transfer has a slight affect on the actual transfer of heat occurring. Extended surfaces in the gas path may be useful, the question of keeping the surfaces clean being the deciding factor. For various reasons small tubes give a higher rate of transfer; smaller dead spaces occupied by cool gases exist and the tubes come into contact with a lesser number of cool gas streams. A steel economiser of the high-velocity (gas and water) type, gives at least 2 per cent. more efficiency than a cast-iron or steel-tube economiser having larger-diameter tubes; but against this must be debited the power necessary for the draught conditions and the extra load on the feed pumps.

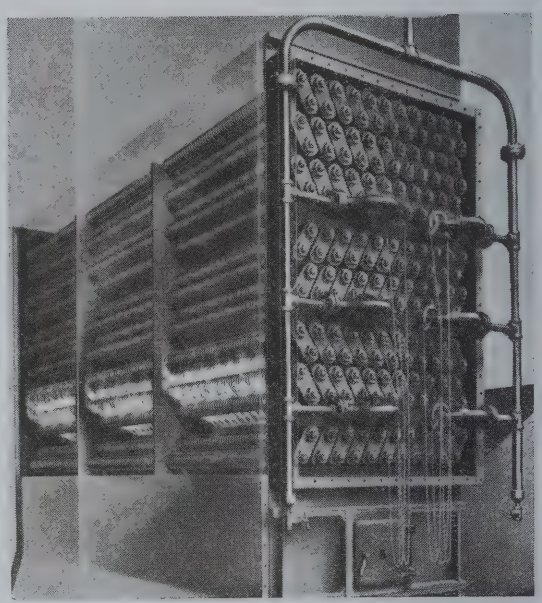


FIG. 5.—*Foster Economiser, shewing method of cleaning tubes.*

Corrosion.

External. It is well known that, if an economiser tube is at a temperature below the dew point of the gases, condensation will occur, and the condensate by absorbing the acids in the gases causes a violent attack on the tubes. From experiments it has been found that the dew point of the gases formed by burning carbon in air is approximately 92 deg. F., and with normal coal of 12,000 B.Th.U.'s containing 3 per cent. moisture, and the CO_2 content of the gases being 13 per cent., the dew point is approximately 101 deg. F. Increase of moisture in the fuel or atmosphere will still further increase this temperature. Accordingly, it is good practice to have the water entering the economiser, at all loads, at a temperature at least equal to the dew point of the gases, preferably not lower than 110 deg. F. when burning ordinary coal. The incoming-water temperature can be elevated by re-circulating a portion of the water leaving the economiser into the inlet side.

Internal. This may be caused by active minerals in the feed-water, but principally by dissolved oxygen, as the temperature in economisers seldom rises to the point at which the minerals become active. It is recorded that the oxygen content of the condensate from a turbine, and at a temperature of 144 deg. F., was 3.5 c.c. per litre as it entered the economiser, but on leaving at a temperature of 260 deg. F. the content was 0.9 c.c. per litre, the remainder using its activities on the material of the tubes.

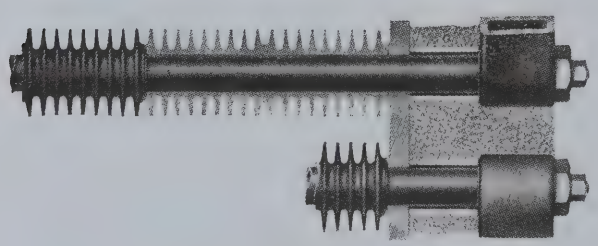


FIG. 6.—*Foster Economiser; construction of manifold end.*

The closed-feed system, although good, does not eliminate the oxygen, and it is preferable with this installation to pass the feed-water through some form of de-aerator. The drawback to these useful pieces of apparatus is the necessity of constant attention, and at cleaning periods oxygen is likely to enter the system.

Evaporators are useful appliances, as the dissolved oxygen is expelled from the system. The oxygen content of water at 212 deg. F. in atmosphere is practically nil, in respect to its corrosive properties, and this suggests a method for its removal. The theory of the high-velocity economiser is that, below the critical velocity the motion is practically a straight line. When this velocity is exceeded the particles become disturbed and a turbulent flow ensues which sweeps away all particles of air which may be attached to the tube walls, owing to the fact that adjacent to the walls the velocity has increased from practically zero to 60 per cent. of the maximum, and the causes of corrosion are removed. Above the critical speed, however, the resistance to the passage of water causes a banking-up effect which resolves itself into a tiny circle of water which is practically stagnant and the air in this section is liberated, with corrosive effects. The use of de-aerators was necessary above and below the critical speed.

Cleaning,

The maintenance of clean surfaces is necessary for continuous maximum efficiency. The method of cleaning the cast-iron vertical type has already been dealt with. The horizontal and steel-tube economisers are kept clean externally by means of various forms of soot blowers, using either steam or compressed air. It has been ascertained that the temperature of the flue gases drops 50 deg. F., on an average, immediately after soot blowing, rising again according to the incompleteness of the combustion of the fuel used. Temperature recorders will indicate the time when soot blowing is necessary, and for continuous running at high efficiency this apparatus is very desirable, on the score of fuel economy. Water has been tried for this purpose, but has led to serious corrosion of the tubes and has been discarded.

Internal cleaning is best carried out by mechanical cleaners, but as this necessitates the shutting down of the plant, treatment of the water before entry is the better plan for continuous efficiency.

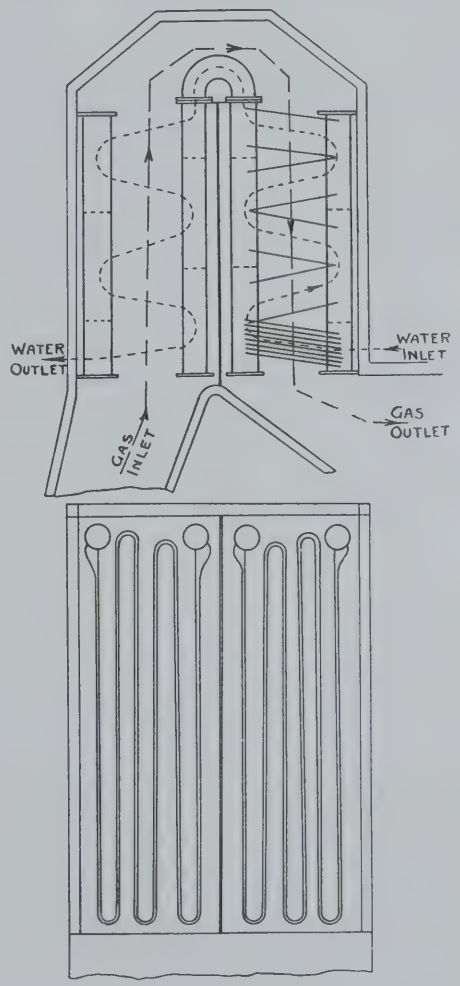


FIG. 7.—*High-velocity Economiser.*

Effective economies.

Fuel Saving. The amount of fuel saved by the use of an economiser is easily ascertained from the temperature rise in the feed-water, compared with the total heat in the steam.

$$\text{Saving per cent.} = \frac{\text{Rise in temp.}}{H - h} \times 100.$$

Where H is the total heat per lb. of steam, and h is the temperature of the feed-water entering the economiser.

Under average conditions, the saving due to the economiser is approximately 1 per cent. for every 12 degrees F. rise in the feed temperature.

The quantity of hot water available is a great asset in industrial process work and larger-sized economisers are installed where space permits, and greater economies are effected than by converting the water into steam and using this again for heating water for essential operations.

Increase in Boiler Capacity. For the same amount of coal burnt, or heat transfer, more water will be evaporated, owing to the lower amount of heat units necessary to convert the water to steam, due to the heat units added by the economiser, the condition in the furnace remaining the same. Approximately, for every 10 degrees rise in feed-water temperature the possible increase in capacity is 1 per cent.

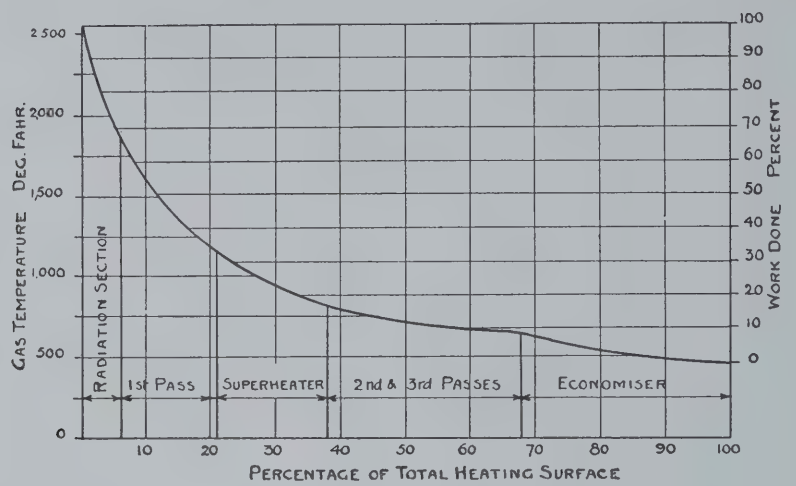


FIG. 8.—*Heat-transfer Curve, illustrating Temperature Differences Obtained and Percentage of Work Done on each pass. Recent Tests on a Boiler Evaporating 7.5 lbs. per foot of Heating Surface, Economiser Heating Surface 60 per cent. of Boiler.*

Maintenance. The introduction of hot feed-water into a boiler reduces the strains, and also the leakage of seams due to cold water impinging on them and causing unequal expansion is eliminated and the life of the boiler lengthened.

(3) THE MECHANICAL STOKER.

By S. McEwen, A.R.S.M., A.I.M.M.

The introduction of mechanical stoking found the boiler room the most neglected department in steam power production plant, and it had to establish its claims for adoption against the strong opposition of the advocates of hand firing. Once the mechanical stoker was installed it was not difficult to effect economies, some of which could not properly be credited directly to the stoker, but were consequent upon the increased attention given to furnace and boiler control, which was encouraged by the application of a relatively expensive machine.

The new industrial science of combustion engineering may be said to owe its present prominence to those associated with the work of designing and operating mechanical stokers. A knowledge of this subject aided materially in extending the adoption of mechanical firing.

The greatest aid, however, to the development was the growth in the size of boiler units following a pronounced and regular increase in the demand for steam. As steam boiler manufacturers modified their designs and enlarged their units in order to meet demands for greater capacity, the mechanical stoker with its attendant equipment of coal and ash handling machinery, became an essential, so that it was no longer a question for debate as to the relative merits of hand firing versus mechanical stoking, but merely of decision as to which of the many types of mechanical stokers available was best suited to the conditions to be imposed upon it.

The enlargement of steam boiler units proceeded continuously, and the stoker manufacturer had to keep pace with this progress. There were periods when the trend of boiler design presented difficulties to the stoker designer, who had to provide adequate grate surface, but new designs of stokers were forthcoming which not only provided for the supply of adequate grate surface in proper proportion to the heating surface of the boiler, but permitted the boiler manufacturer to take further steps in increasing the size of his unit.

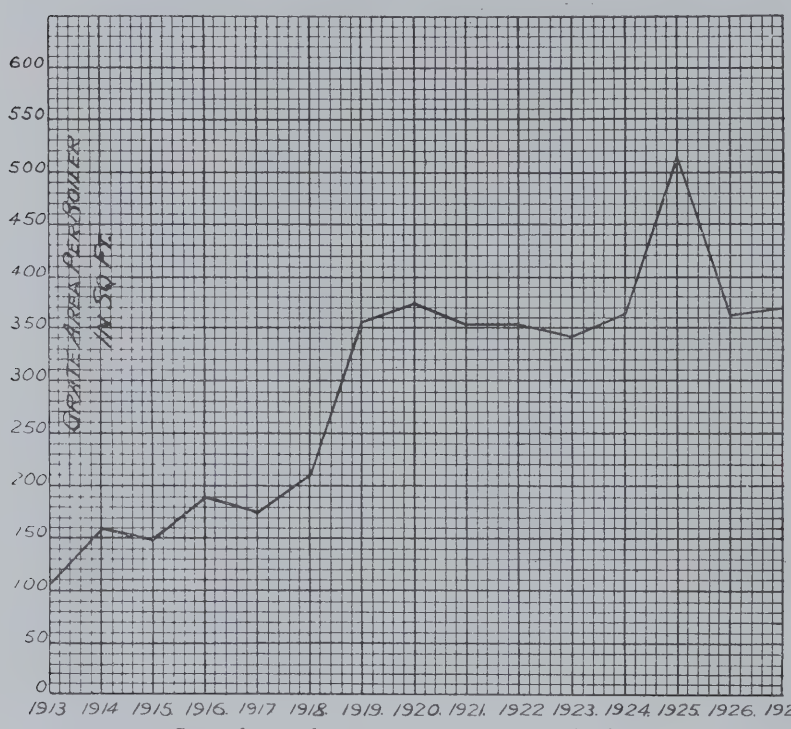
The upward trend in the capacity of steam boiler units, however, ultimately resulted in demands on the stoker maker, which became more and more difficult to meet. Single stokers 20ft. wide and 24ft. long had been made and put into successful operation, but still the floor space available became inadequate to provide the requisite grate area to meet the requirements of a boiler which confined its heating surface within a much smaller space than was previously current practice. Moreover, the heating surface which was provided was made more efficient and was expected to transmit an increasing quantity of heat per square foot with each succeeding improvement in design.

At this stage an alternative to the mechanical stoker became available, namely, a system of combustion of fuel in powdered form. This had the advantage of almost indefinite expansion and could more than keep pace with the increased steaming capacity of boiler units without occupying more than the prescribed floor space. The introduction of powdered fuel firing enabled boiler units to increase in capacity beyond the range which was considered reasonable for the application of mechanical stoking of unpulverised fuel.

This increase in grate area per boiler is illustrated by the accompanying curve (Fig. 1), which has been prepared from a stoker manufacturer's records. The period from 1919 to 1925 shows very little increase, but it is interesting to note that during that period the evaporative capacity of the boilers equipped increased by thirty per cent., and this was provided for by improvements which permitted a higher efficiency and a higher rate of combustion per square foot of grate area. From 1925 the selection of coal firing equipment of the larger boiler units tended to be in favour of powdered fuel systems.

While the large boiler unit has become established in large central power stations, there continues to exist a demand for smaller units and these collectively exceed in capacity that of the relatively few extremely large units. Thus, there are an enormous number of boilers in existence and probably an even larger number of boilers to be manufactured and supplied in the future which will have a capacity well within the range of application of mechanical stokers. It must be realised, however, that the successful development of powdered fuel systems has had a natural consequence in a very active endeavour to determine to what

extent such systems could be applied to the smaller boiler unit in place of mechanical stokers, which latter have admittedly been developed to secure what unquestionably is a very high combustion efficiency coupled with reliability of performance. This enquiry may be said to be still proceeding, and as the combustion of powdered fuel is a comparatively new method and is being rapidly developed, it is at this stage impossible to predict what progress will be made in extending its range downward from the very large boiler units for which it is particularly fitted. It is certain that its scope of application will be increased, but there is no reason to believe that its scope can ever be increased to the extent of excluding entirely the mechanical stoker. At the present time there is a very definite field for stokers, the permanence of which depends upon the work of engineers and inventors responsible for the development of powdered fuel firing systems.



Curve shewing the maximum grate area provided for a single boiler in successive years.

The selection of fuel firing equipment is governed to a very large extent by local conditions, and, while mechanical stokers have been perfected to secure the maximum efficiency of combustion, there is still a demand for a cheaper firing equipment which will operate at a lower efficiency, but which will secure the greatest return for the purchaser. For example, in a district where fuel of good quality and of a suitable physical condition can be purchased very cheaply, the relative value of the effective utilisation of the maximum amount of heat and of minimising capital expenditure may be largely in favour of the latter. If, at the same time, the load factor of a plant be very low, the balance in favour of the cheap plant is increased. The selection, therefore, of firing equipment does not depend entirely upon efficiency of combustion alone, but is also dependent upon other factors, and this will have material bearing upon the continued use and development of mechanical stokers. Stoker makers will continue to improve their designs in order to reduce cost of installation for a specific performance and, while in the case of the available more expensive equipment there is very little scope for further increase in combustion efficiency, there is always scope for improvement in design which will reduce cost of installation and of maintenance.

Associated with the development of mechanical stokers has been the development of furnace design and, following the increase of knowledge of the subject of combustion engineering, the relative importance of the furnace of a boiler and of the heating surface suffered a reversal. Originally, the high-pressure units of a boiler were all important. Subsequently the disposition of the heating surface of a boiler had to be made to conform to requirements imposed by satisfactory furnace design.

Progress in the design of stokers was marked by active competition, which made known the merits and demerits of natural draught, induced draught, forced draught, hot air, cold air, combustion arches, archless furnaces, under-feeding, over-feeding, horizontal feeding, and many other variations well known to those who have been called upon to adopt a method of firing for steam boilers.

Throughout years of sustained effort, the ultimate aim of the stoker designer has been very apparent. Compromises have had to be adopted from time to time, and will continue to be adopted, but a long experience in noting the demands of those responsible for the construction and operation of boiler plants

show clearly that the perfect mechanical stoker should be capable of burning the widest range of fuels available so as to make the operator independent of any particular class of coal and enable him to take advantage of any favourable fluctuations in the market. The stoker must be flexible to the extent of being able to meet widely varying conditions of load without material change in efficiency, be continuous and uniform in its operation, be amenable to automatic control, and be reliable with a minimum of cost of maintenance for the stoker itself and for the furnace brickwork. Stoker manufacturers may now justly claim that provided local conditions justify the capital expenditure, these characteristics can be embodied in a modern mechanical stoker equipment.

Boilers fired with mechanical stokers have been operated to secure an efficiency of steam generation equivalent to 87 per cent. of the gross calorific value of the fuel.

There have been many factors which have been the subject of the closest possible investigation governing present-day practice with mechanical stokers, and the following reference is made to a few of the more important of these factors.

Rate of combustion.

It is natural in the attempt to secure the greatest liberation of heat from a given grate area, to determine what is the limit in the rate of combustion of coal per square foot of grate. The rate of combustion in the earliest practice was very low, while to-day it is the practice in some of the American power stations to operate stokers and burn coal at the rate of between 60 and 70 lbs. per square foot. In striving for this high rate of combustion, efficiency was not the sole consideration. Most power stations have a peak load and if, therefore, for short periods a stoker is capable of burning fuel at a 25-30 per cent. higher rate of combustion per square foot than is desirable to yield the maximum efficiency of combustion, it is profitable to suffer some loss of efficiency in order to avoid the necessity of installing additional costly equipment for operation during short periods only. The nature of coal burned, however, largely governs the rate of combustion which is possible, and in this country such high rates are not customarily attempted although, during recent years, the average rate of combustion has been materially increased. One determining factor in the past on the rate of combustion has been maintenance of brickwork. With high rates of combustion the velocity of the products of combustion over the furnace arches and walls was so high as to cause rapid deterioration and high cost for maintenance. With the improvement of furnace design, higher rates could be adopted without undue cost for maintenance. This improvement in the design, which includes the possibility of installing water-cooled furnace walls, has now reached a point where the only consideration of determining the limit for rate of combustion is efficiency. An excessive velocity of air through the fuel bed results, with most English coals, in lifting from that fuel bed some of the smaller particles of fuel which are carried in suspension and again deposited in a part of the grate where the velocity is low. This results in an uneven fuel bed, irregular combustion and usually involves a high percentage of combustible in the ash. Another factor which had its influence in keeping the rate of combustion within low limits, was the durability of the grate surface. In the earlier designs of grate surface an excessive furnace temperature resulted in the overheating of the grate, leading to mechanical breakdown and to partial or complete destruction. With a better understanding of application of air distribution it has been possible to secure durability for a grate even with very high furnace temperatures. Before success was achieved in this direction, the metallurgist was called upon for aid to secure the supply of metals and alloys of special composition, but greater success was ultimately achieved by better application of principles of air distribution and air cooling.

Riddlings.

Following the attempt to burn finely divided coal, which had the advantage of yielding a cheap heat unit, one of the hardest problems to solve was presented by what were called riddlings. To minimise riddlings, the air spaces had to be small enough to prevent coal from passing through. This entailed the use of forced draught in order to pass the requisite quantity of air for combustion through restricted

openings. To preserve the fine air spaces in a grate which was subjected to high temperatures, necessitated a great deal of investigation and thought, but the problem did not prove insuperable. Some riddlings, however, must be expected even with the use of very fine air spaces, and the automatic removal of these so as to prevent accumulation of combustible material within the forced draught air chambers made further demands upon the designer and partial or complete solution of the problem has been effected in a variety of ways.

Heated air.

The advantages to be derived from the use of heated air in the efficient utilisation of fuel were always apparent, but its application presented a problem of some magnitude to the stoker designer. Difficulties had been encountered in the past in the provision of a grate surface which would stand high temperatures of combustion and it was realised that the use of heated air would increase the temperature of combustion. However, the principles which had been exploited in increasing the durability of grate surfaces and of furnaces, needed only a more extended application in order to cope with this further demand which was made by the application of hot air. The higher the furnace temperature which could be maintained, the greater the amount of heat which could be absorbed by a given heating surface exposed to that temperature, and this, together with the fact that the air heater is able to provide a relatively cheap heat absorbing surface, was sufficient to ensure that the use of heated air would be increasingly adopted. At the outset the combustion engineer was not called upon to supply hot air to mechanical stokers at a higher temperature than about 200° F., but progress in this direction quickly raised these temperature to 300° and 400° F., and there are records of some cases where air at a temperature of over 500° F. has been used. With water-cooled furnaces, large combustion chambers and stokers representing the latest development of construction, these high temperatures in the future are likely to be adopted securing the maximum efficiency, with a minimum of capital expenditure.

Automatic control.

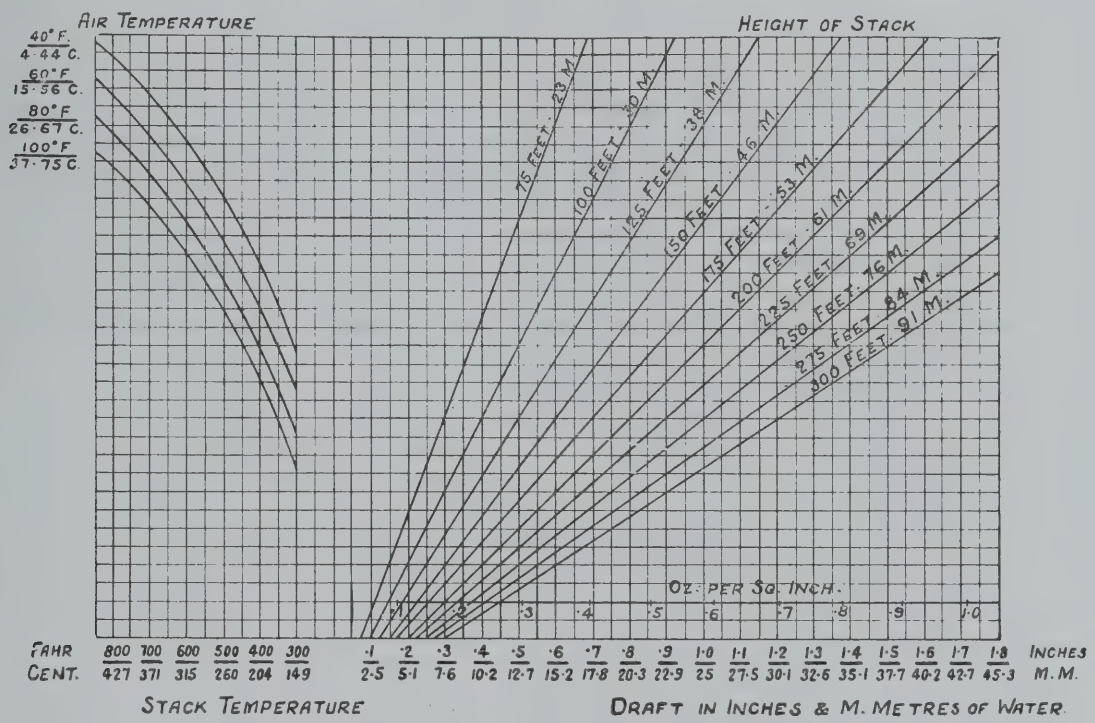
Systems have been developed by means of which it is possible practically to eliminate the human element in stoker operation. The feed of fuel with the requisite air supply for its combustion can be automatically controlled by the steam pressure gauge. The air supply can be controlled to maintain uniformly the desired percentage of CO_2 and the air pressures and draughts can be adjusted automatically to maintain predetermined differentials of pressure between the air chambers, the furnace and the boiler outlet. These automatic controls are costly and the expense can only be justified when applied to very large units; their adoption in this country has not been favoured, but really excellent boiler-house performance has been secured by the free utilisation of recording apparatus and by systematised inspection.

(4) THE ECONOMICAL VALUE OF MECHANICAL DRAUGHT.

By J. W. Gibson, A.M.I.E.E.

Natural draught and its limitations.

The primary object of a chimney is to carry away the waste gases resulting from the burning of the fuel. Under natural draught conditions the chimney has also to provide sufficient draught intensity to overcome the resistance through the boiler passes and flues and the bed of fuel on the boiler grates. The volume of these gases and the permissible velocity determine the cross section of the flues, and the chimney, while the intensity of the draught is governed by the height of the chimney and the difference in density between gases in the chimney and the outside air. It will be found that the chimney draught will vary approximately as the product of the height of the chimney and the difference in temperature inside and outside the chimney.



Curve showing the theoretical Draught produced by chimney stacks of different heights with different temperatures of flue gases and of atmosphere.

The chart presented shows the theoretical draught power of chimneys of different heights and for varying inside and outside temperatures. A glance at the chart will show that to provide even a moderate draught the chimney has to be of a considerable height, and that the temperature of the gases leaving the boiler has to be much higher than is consistent with the best boiler efficiencies. Not only is the capital cost of the high chimney with its elaborate foundations necessary with natural draught, but the moderate draught which it is capable of producing seriously limits the adoption of heat-saving devices, and necessitates working the boiler with thin fires, with all the attendant disadvantages.

In tropical countries where the sun temperature may rise to 180° F. a chimney of sufficient height to produce even very moderate draught will be found almost impracticable. Again, natural draught is largely influenced by the outside atmospheric conditions, and in many instances the heavy demand for steam may coincide with the worst conditions for natural draught, thus crippling the boilers when they are most required. Apart from natural draught the passage of the gases may be accelerated in five ways, these

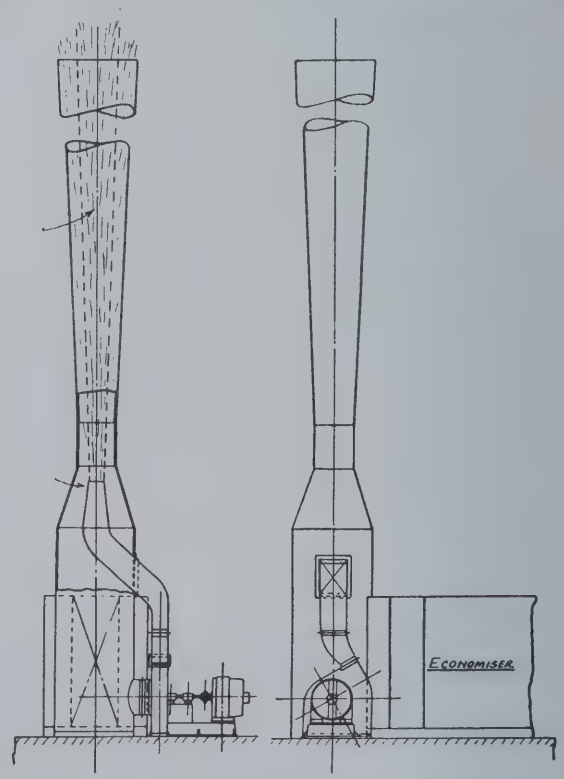
being: (1) Steam jets, (2) ejector draught, (3) induced draught, (4) forced draught, (5) balanced draught. Each system possesses certain advantages and certain drawbacks, and a brief review of the chief features of each is given below.

Steam jets.

Practically the only advantage that can be claimed for the steam jet, whether supplied as an exhauster in the base of the chimney, or as forced draught in the ashpit, is its low first cost. The chief drawbacks to its use are as follows: (*a*) Heavy running cost; (*b*) if used as forced draught, the lowering of the furnace temperature; (*c*) possibility of pitting and corrosion. A recent comprehensive test on steam jet systems revealed an average steam consumption figure of 6.65 per cent., whilst with some plants it rose to the extraordinary high figure of 18 per cent. under average conditions; the power consumption is three times as much as could be expected with an efficient system of mechanical draught. Assuming that the calorific value of the fuel is 12,000 B.Th.U.'s per lb., then 6.65 per cent. of this figure, or 798 B.Th.U.'s, would be required for steam jet draught purposes. Steam jets are more usually applied to boilers of the Cornish and Lancashire type.

Ejector draught.

With this system the draught is produced indirectly by discharging air at a high velocity through a nozzle placed centrally in a Ventura-shaped chimney. There are two types of this ejector in service. In the first, the air at atmospheric temperature is discharged through the nozzle, and the advantage claimed is that the fan and fan bearings are not subject to the effects of high temperature waste gases. In the second type, a portion of the waste gases is handled by the fan, which is usually placed in the base of the chimney, and discharges these waste gases at a high velocity through the internal nozzle. With this type, the fan is in a very inaccessible position, and both shaft and bearings are subject to the high temperature of the waste gases. The bearings are furthermore not usually water-cooled.



Sketch illustrating Ejector Draught.

The ejector system relies largely upon the natural draught of the chimneys, which are usually constructed of sufficient height to give a natural draught power of $\frac{5}{8}$in. to $\frac{3}{4}$in. water-gauge. In their original claim the designers of this system stated that the fan was merely intended as an accelerator to the natural draught effort of the chimney. The effect of the high-pressure air or gas in the inner portion of the chimney increases the natural draught power by .25in. to .5in. water-gauge, making a total effective maximum draught in the neighbourhood of 1.25in. water-gauge. To produce the necessary velocity in the internal nozzle requires a pressure of 4in. to $4\frac{1}{2}$in. water-gauge. It is obvious that when the fan is handling a portion of the waste gases from the chimney base it will have to overcome on the suction side the negative pressure set up by the action of the nozzle, and this work is in addition to that represented by the pressure required in the central nozzle. If the draught power set up by this apparatus is 1.25in. water-gauge at the chimney base, and 4in. water-gauge pressure is required in the central nozzle, the fan has to operate against a total head of 5.25in. water-gauge and will require power in proportion. This condition is very much aggravated if any further increase in draught power is required.

The horse-power required to convey a quantity of air—V—cubic feet per minute, against water-gauge (W) inches, is given by the formula: $\text{H.P.} = \frac{5.2 \times V \times W \times 100}{33{,}000 \times \text{efficiency per cent.}}$. In an ejector draught system at least one third of the gases pass through the fan at about 4½in. water-gauge to induce a water-gauge of 1in. at the base of the chimney.

Neglecting entirely the natural draught effect of the hot gases the horse-power upon the fan shaft will be: $\frac{5.2 \times 5\text{in.} \times 1/3\ V. \times 100}{33{,}000 \times \text{efficiency}}$, where V=the volume of waste gases.

Under ordinary induced draught conditions the power upon the fan shaft will be $\frac{5.2 \times 1 \times V \times 100}{33{,}000 \times \text{efficiency.}}$ The power in the two cases will, therefore, be in the proportion of $\frac{5}{3}$ to 1, and shows that the ejector draught fan requires, when producing the same water-gauge and under otherwise similar conditions, about 65 per cent. more power than the ordinary induced draught fan. In an ejector chimney there is a throat of comparatively small cross section immediately above the nozzle, through which all the gases have to pass at a high velocity. An increase in the volume of gases due either to increased load or to a lower percentage of CO_2, will result in a corresponding increase in velocity through this small cross section, and, as the resistance to the flow varies as the square of the velocity, the resistance will be greatly increased. For this reason ejector draught has not the flexibility of induced draught. With the higher draught intensity required for the economical combustion of low-grade fuels, the pressure which would have to be set up by a high-pressure fan on the ejector system would be excessive, and the power required would rule it out of consideration when compared with an ordinary induced draught installation.

Owing to the high velocity in the internal nozzle the stream line through the chimney flows at a very high rate at the centre, and very much slower at the outer perimeter. It might be expected that the difference in the velocity of the air or gas passing through the centre nozzle, compared with that flowing by induction through the annular space around the nozzle, would gradually average out before being discharged to atmosphere. Such, however, has proved not to be the case, and the very high velocity in the centre of the chimney is fairly well maintained to the top of the chimney. There is, therefore, very little possibility of settlement of the dust within the chimney base, and any dust which is in suspension is discharged into atmosphere. This disadvantage of dust emission is not serious when fuel of relatively low ash content is used, but may develop into a serious nuisance where the ash content is in the range of 15 to 28 per cent. The mechanical efficiency of this system at 1¼in. water-gauge is usually found to be in the neighbourhood of 30 to 35 per cent.

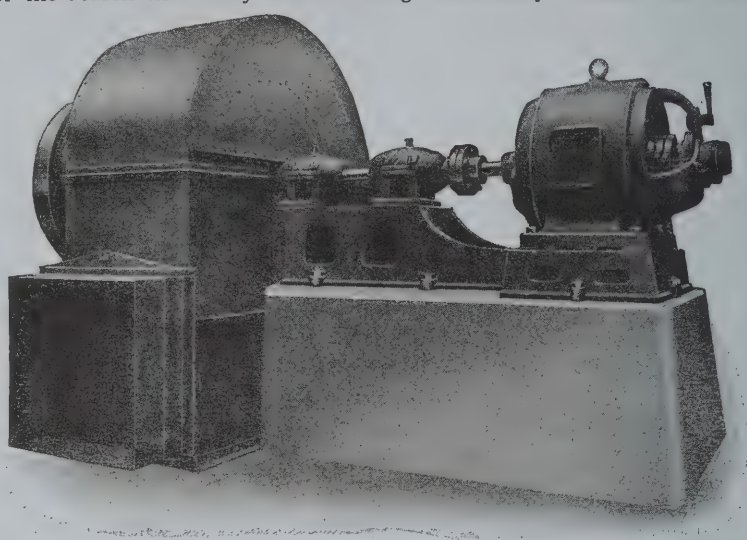
Induced draught.

In this system the fan is placed near the chimney base and arranged to draw the waste gases through the fuel bed, boiler, flues, etc., and discharge into the chimney. Fans applied in this manner have for many years given such excellent service that they have now become an integral part of practically any new boiler installation. The system possesses a marked superiority over the two systems previously described, particularly as regards power consumption and flexibility of control and can accomplish more economically any duty coming within its range.

To obtain the best results it is essential that certain fundamental principles be thoroughly understood and intelligently applied, when satisfaction can be confidently assured. In the first place, it does not seem to be generally appreciated that the differences in pressure met with in induced draught are of a small order of magnitude, and, consequently, losses in draught, which at first sight may appear to be negligible, will, on closer examination prove to be of considerable importance, the proportion of the losses to the total draught being very high. The differences of pressure are nearly always measured by the level of the water in the legs of the U tube. A cubic foot of water measures in weight 62.4 lbs., so that the pressure exerted by a column of water 12 inches high is 62.4 lbs. per square foot. The differences of pressure most usually encountered in induced draught work will be from ¾in. to 3in. of water column, or from .027 to .108 lbs. per square inch. It will, therefore, be readily seen that losses which might be per-

missible on a water system where the pressure ranges up to 1,000 lbs. per square inch would be quite inexcusable in an induced draught system. The successful application of induced draught depends upon the close observance of certain rules, the chief of which are: (1) The gases must be led to and from the fan by the easiest path, and all sudden change of velocity and direction avoided; (2) care must be exercised to prevent infiltration of air.

Sudden changes of velocity and direction must be avoided throughout the whole path of the gases from the furnace to the chimney, for the reason that every sudden change in velocity means a loss of head at least equal to the difference in water-gauge required to set up these velocities. A sudden change in direction necessitates overcoming the inertia of the gases in the original direction and the establishment of the velocity in the new direction. Due to the inertia also, the effective cross section at the change of direction will be much less than the actual cross section, and the actual velocity of the gases at this point much higher than would be obtained, by dividing the volume of the gases by the cross sectional area. It will be at once apparent that since the water-gauge required to set up a velocity varies as the square of the velocity, sudden changes of cross section must be rigorously avoided, and that the same remark applies to changes of direction. In cases where changes of velocity are absolutely unavoidable, the change in the cross section of the flue should be made gradually, and where the direction has to be altered, large radius bends should be used. Infiltration is a prolific cause of low boiler efficiency. Under induced draught conditions the water-gauges encountered are usually higher than under natural draught conditions, and, therefore, the quantity of cold air drawn through any crevices in the brickwork of the flues will be greater than with natural draught. With different types of boilers, varying amounts of infiltration may be anticipated. For instance, the leakage into the flues of a Lancashire boiler installation will usually be much greater than the infiltration on a battery of steel cased water-tube boilers. For this reason care should be exercised to keep the brickwork well pointed. In a large number of boiler installations it is considered desirable to have provision made to run the boilers on light load with natural draught, and this can be arranged by the use of suitable dampers which isolate the fan. Care should be taken to ensure that all dampers are a good fit, as any leakage through these will short circuit to the fan suction, thereby lowering the effective water-gauge set up by the fan and increasing the power consumption.



Typical arrangement of a "Sirocco" Induced Draught Fan.

Dampers can be arranged at the fan suction and discharge, so that the fan may be entirely cut off from the flues if desired. They should, however, be used solely as isolating dampers, and not for regulation, excepting in exceptional cases, where specially designed for this purpose.

Design of fan.

In designing a fan for a particular boiler installation, many different factors have to receive due consideration, and it cannot be too strongly impressed upon the steam user who is contemplating the adoption of induced draught that the fullest possible particulars should be given to enable the fan maker to put forward a suitable plant. The volume, water-gauge, temperature and efficiency are interdependent,

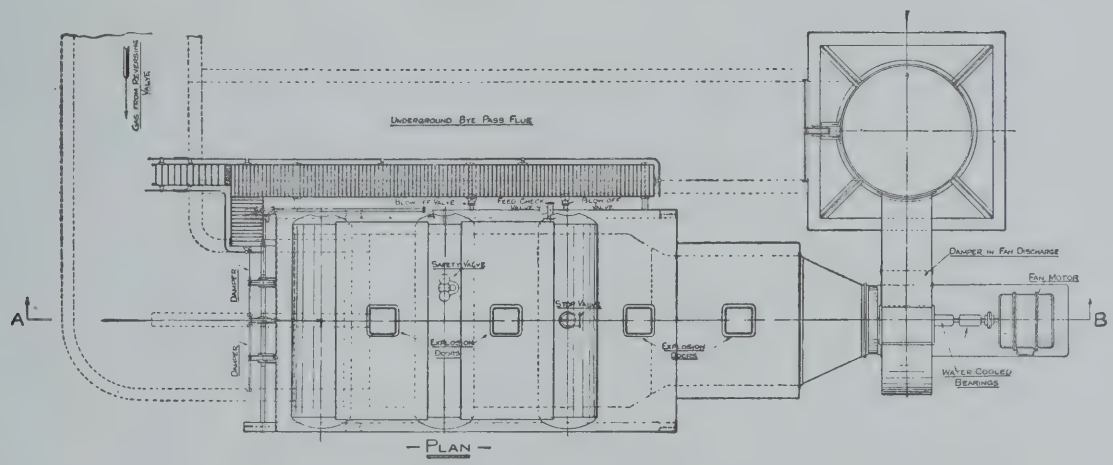
and the fan must be proportioned for each duty so as to give the highest efficiency. Unless, therefore, these figures are given, or alternatively, particulars from which they can be calculated, it is impossible to put forward a plant which will be the most suitable for its specific duty. The following are some of the data which a fan-maker requires to know:—

Type of Boilers. Particulars as to the type of boilers must be given, as the resistance to the flow of the gases through a boiler varies with the different makes, and, indeed, with different designs of boilers of the same make, depending on the method of baffling adopted.

Accessories in Use. It is also necessary to know whether the boiler is fitted with economisers, superheaters, or air heaters, as these accessories will not only increase the water-gauge required, but also lower the temperature of the gases at the fan.

Rate of Combustion. The rate of combustion per square foot of grate area must be known, since obviously a greater pull is required to induce the necessary amount of air through a thick bed of fuel than through a thin one.

Class of Fuel. The class, size and grade of fuel also require to be taken into account. Small coal will pack more closely on the grate than the larger sample, and, therefore, requires a higher draught. Coal which tends to cake will also offer a higher resistance to the passage of air through it than coal low in volatiles, and, therefore, with no tendency to form a spongy mass upon the bars. Again, some fuels, particularly those approaching anthracite, require a fairly high velocity of air through them, whilst others give better results with a less intense draught.



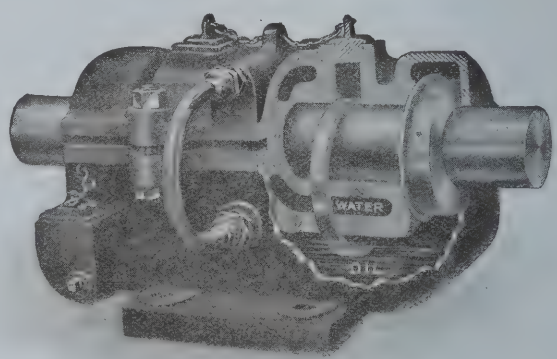
Typical Arrangement of Stirling Boiler with a "Sirocco" Induced Draught Fan and Chimney.

Method of Drive. The type of drive, whether motor, engine or belt, is also of importance. In large generating stations it will probably be found most convenient to adopt motor drive, whilst in many manufacturing concerns using large quantities of low-pressure steam for process work, it is often advantageous to adopt steam engine drive and utilise the exhaust from the engine in the factory. In this connection, it is of interest to note that since the latent heat of steam rises slightly with reduced pressure, the value of low-pressure steam for heating purposes is almost the same as high pressure, so that in the circumstances instanced above the power for driving the fan is obtained practically gratis. Whenever possible provision should be made for varying the speed of the induced draught fan to suit the load on the boilers. With steam drive this is easily secured by throttling with the stop valve, while direct-current shunt-wound motors can be arranged to give wide speed variations by shunt control with high efficiency. Alternating current motors, on the other hand, are practically fixed speed machines, and consequently far more care has to be exercised in anticipating correctly fan duty when the drive is to be of this type. Alternating current-wound rotor slip-ring machines can be arranged

O

with speed control by rotor regulation. This will give a choice of speeds over a range to about 30 per cent. below maximum. Power is, of course, absorbed in the rotor resistance, but the total power input is considerably reduced at the lower speeds.

This system is quite a good one to adopt in cases where the boilers are operating under varying loads, but in cases where the boilers may be operating for long periods at normal loads, and only for short periods at peak overloads, alternating current motors of the two-speed type can with advantage be adopted. With this type of machine no resistance is in circuit, but there is the choice of only two speeds. These machines are now standard with well-known makers and have the advantage of being inexpensive. The trend of modern practice is to avoid belt drive where possible. If the fan is to be driven from existing line shafting the fan shaft must be parallel with the line shaft, and this fact alone often precludes the possibility of applying the fan in a really efficient manner. Also the temperature near the induced draught fan is generally higher than is conducive to the best results with belt drive. Large fans usually require to run at a low speed. If direct coupled, the motor would be larger, and consequently cost more than a standard high-speed machine. With belt drive, a high-speed motor may be used, and the fan driven at the required speed by suitably proportioning the pulleys on the fan and motor spindles, but it is very problematical if the reduction in cost thus effected is justified.



"Sirocco" Ring Lubricated, Water-cooled Bearing.

As an alternative to belt drive, chain drive is sometimes adopted, and modern inverted tooth silent chains have reached a high stage of efficiency, and in special cases may be well worth consideration.

Forced draught.

In the induced draught system the air for the combustion is drawn through the fuel bed, whereas forced draught sets up a pressure under the fires, thus forcing the air through the fuel. Forced draught probably owes its inception to marine practice, but its use has gradually extended to land installations as well. With this system the function of the fan ends when the air for the combustion has been forced through the fuel bed, the remaining duty of overcoming the resistance of the boilers and flues being taken care of either by natural draught, or preferably by induced draught. The combination of forced and induced draught is termed balanced draught, and is dealt with subsequently. With a forced draught system the pressure that can be maintained below the fires is governed by the necessity of preserving a slight vacuum above the fires. Unless this condition is maintained flames, smoke and hot gases will be blown through every opening and crevice in the combustion chamber. This not only results in a considerable heat loss, but makes the vicinity of the boilers uncomfortably hot. The pressure usually required at the fan outlet for forced draught is between 3½in. and 4in. water-gauge for retort and compartment stokers, and between 1½in. and 2in. water-gauge for chain grate stokers, but where the duct is unusually long or of curtailed area, slightly higher pressures are required to overcome the additional resistance.

Balanced draught.

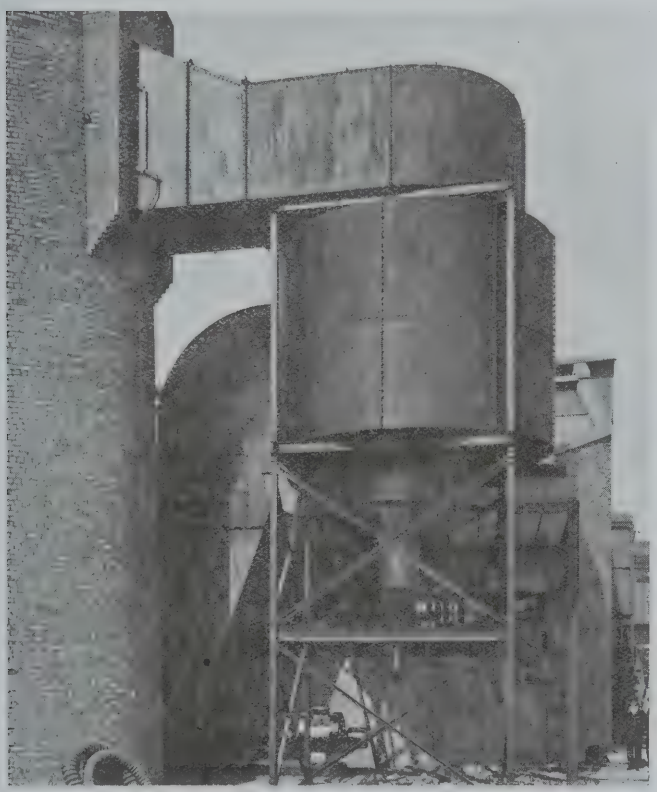
The balanced draught system possesses the advantages of both forced and induced draught, and is very generally in use in modern power stations. With this system the forced draught fan overcomes the resistance of the air preheater (if fitted) and of the fuel bed, whilst the induced draught fan picks up its load from the top of the fuel bed, and thus, has only to deal with the resistance of the boiler, economiser and preheater (if fitted). Owing to the present demand for high rates of combustion and the introduction

of many economy devices, all of which offer a considerable amount of resistance to the flow of the gases, an induced draught fan would often have to set up such a high water-gauge that exceptional attention would have to be paid to the brickwork to prevent infiltration.

Balanced draught, in addition to providing means for burning fuel under the most efficient conditions, is very elastic and allows a wide range of boiler output without any sacrifice in fan efficiency. If a speed range is provided on both forced and induced draught fans, the intensity of the draught set up by either fan can be regulated exactly to suit requirements. The condition of draught immediately over the fire is practically balanced; it is only necessary to maintain a slight vacuum in the combustion chamber, about 0.1in. to 0.2in. water-gauge, to prevent the escape of the gases, and to ensure that any small leakage may be inwards. In many stations the balanced draught system is operated so that the induced draught fan takes care of the light loads, the forced draught fan being brought into action for normal and overloads.

Self-contained units.

With the increase in the size of boiler units it is now becoming very general to make each unit entirely self-contained. Instead of one forced and one induced draught fan serving a battery of boilers, it is now quite common to find each boiler equipped with its own forced and induced draught fan and its own chimney. The success of this type of arrangement depends largely on the load factor, and is usually more suitable for power stations where the load varies throughout the day, than for industrial concerns where the load is practically constant. In a power station a portion of the boiler plant will often be able to carry the entire load at all times excepting the peak, and consequently a number of boilers will be banked throughout a greater portion of the day. If the draught is created by one fan, and more especially if its speed be a fixed one, this may mean that the fan may be running for long periods at less than its maximum efficiency. On the other hand, if each boiler unit is self-contained, the fans upon the boilers in actual operation will be working at maximum efficiency, whilst those upon the banked boilers will be entirely shut down. In industrial undertakings the boiler units are usually smaller than in power stations, and consequently the advantages of the self-contained unit system are not so marked. It should, however, not be overlooked that a single mechanical draught unit usually implies longer flues than the self-contained system, involving therefore greater risk of infiltration through brickwork.



General view of Davidson's Dust Collector installed at an Industrial Works.

Balanced draught has proved its merits during the long coal strike of 1926 when fuel for all purposes was scarce and expensive. In many cases very low grade of fuels, practically looked upon as waste, could be used. In some cases the ash content was as high as 40 per cent. In others coke breeze was used, either alone or sandwiched along with low-grade bituminous slack. In all cases the wide range of draught control proved effective and helped to tide over this very anxious time, it also served the valuable purpose of demonstrating that under the wide range of adjustment and control of balanced draught conditions, practically any grade of fuel can be utilised.

GRADING TESTS OF FLUE DUST CAUGHT BY DAVIDSON PATENT FLUE DUST COLLECTOR.

	Screen.		Results obtained.									
	Grade of Screen. No. of Mesh.	Number of Apertures per sq. in.	Bargoed Power Station, Powell Duffryn Coal Co.	Shoreditch Station.	Beckton Gas Works.	Central Electric Station.	Nechells Power Station, Birmingham.	Lessines Power Station, Belgium.	The Mint, Hyderabad, India.	L.C.C. Power Station, Greenwich.	Grimsby Power Station.
			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Remained on ..	60	3,600	19.75	19.75	40.6	4.9	0.73	1.6	0.2	26.4	9.6
Passed through ..	60	3,600	80.25	80.25	59.4	95.1	99.27	98.4	99.8	73.6	90.4
Passed through ..	80	6,400	36.0	60.5	54.6	90.0	95.86	92.7	99.6	62.6	79.25
Passed through ..	100	10,000	36.5	59.6	32.2	85.3	94.0	90.0	99.4	58.8	76.8
Passed through ..	120	14,400	34.0	58.8	36.7	77.0	93.22	79.0	98.8	46.4	65.5
Passed through ..	200	40,000	18.5	36.0	16.35	16.85	64.62	52.2	95.2	24.4	43.2
Class of Fuel			Small Coal and Refuse from Washery.	75% Whitwick Slack, 25% Scotch Washed Peas.	Coke Breeze.	Washed Peas.	Slack Dust and Coke Breeze.	Pulverised Fuel containing 26% Ash.	Singareni Slack, containing 28% Ash.	Northumberland Steam, Small.	Yorkshire Slack.

Bearings.

Bearings of the induced draught fans require to be of generous proportions, and in addition to continuous ring lubrication the bearing next the casing of the fan should be water cooled. Large surface of contact between bearing and journal assist in the transfer of heat, and in addition to keeping the bearing cool, water jacketing prevents heat from the waste gases creeping along the shaft to the motor.

Pulverised fuel.

Owing to the high degree of combustion aimed at under pulverised coal-firing conditions, it is necessary to have a wide range of draught power adjustment on both forced and induced draught fans. Direct current shunt-wound variable-speed motors are most suitable, and in the case of alternating current supply the motor should be of the wound rotor type with rotor resistance speed control, or of variable speed commutator type. On the other hand, draught power may be controlled by damper regulation, and whilst this is quite a satisfactory method, it is more expensive in power consumption.

DUST AND GRIT COLLECTORS.

Much attention has been given during the last few years to the prevention of the emission of excessive quantities of flue dust from power station and factory chimneys, and this point has been taken into account in the new Public Health (Smoke Abatement) Act, which has this year come into force. In this Act, although it applies to "Smoke Abatement," the expression "smoke" includes dust, grits and any solid matter carried in suspension in the waste gases. The necessity for the maximum economy in coal consumption has automatically overcome the smoke nuisance, by providing better combustion conditions, but the more extended use of low-grade fuels with a higher ash content has considerably increased the emission of flue dust at power station chimneys. Dust emission was not looked upon as a serious matter when better fuels were used, and in the larger American power stations where stoker-fired boilers are fitted and where the fuels used contain from 5 to 7 per cent. of ash there is very little to complain of in regard to dust emission. In the

case of pulverised fuel-fired boilers it is only where the power station is situated in or adjacent to residential areas that there is any cause for complaint. In the newer stations provision has been made for preventing the discharge of the fine ash which arises from powdered fuel-fired conditions. It is to be expected that when using good fuels the relatively small amount of dust carried away in suspension would be dispersed over such a wide area that it may not be looked upon as a serious matter. It is, however, different when fuels are used containing from 15 to 28 per cent. of ash. The flue dust collector illustrated can be applied to a gas circuit either adjacent to the chimney, or on the chimney itself, and has proved an effective means of overcoming this dust difficulty. The apparatus is capable of dealing with dust of extreme fineness either from stoker-fired or pulverised fuel-fired boilers. A table is given showing the sieve analysis of dust caught by the apparatus, from boilers operating under both conditions of firing.

The average rate of dust collected at a number of London stoker-fired power stations amounts to 0.45 per cent. of the total coal consumed upon the grates, but in the case of pulverised fuel-fired boilers the amount of dust caught in suspension at the chimney varies, according to the class of coal, from 5 per cent. up to 10 per cent. of the total coal consumed. Fuels having, approximately, the same ash content will vary considerably in regard to the character of the dust. In some cases the finer particles fuse together, and in other cases the particles split up. This peculiarity will be clearly noted from the sieve analysis in accompanying table. As the dust-collecting apparatus must deal with all the products of combustion, it is of rather bulky proportions, and one of the principal difficulties is to find accommodation for it. To meet this difficulty three different types have been invented, all of which follow the same principle of centrifugal separation. The main points which have to be kept in mind in the designing of the apparatus is to obtain the highest possible collecting efficiency, whilst at the same time keeping the resistance down to a minimum.

An illustration is shown of the Davidson patent shunt pressure-type collector applied to a chimney serving six Lancashire-type boilers. The works are situated in a residential area and no complaints of dust emission have been received. The amount of dust collected on this installation is one ton per day, all of which would have been carried out in suspension in the waste gases if the collectors had not been applied.

(5) THE AIR PREHEATER.

By P. H. N. Ulander.

One of the most remarkable developments in boiler house practice during the last ten years has been the introduction of the air preheater.

Land and marine practice have for a long time moved in different directions. The land installation was altogether dependent on the economiser for the recovery of the low temperature heat from the flue gases, whereas the marine installation, on account of weight, was forced to use the air preheater.

With increased boiler rating and the use of extensive feed heating the economiser alone was not able to recover enough of the waste heat, and at the same time give a good return on the capital invested.

A great obstacle to the introduction of the air preheater was the difficulties foreseen in regard to furnace refractories and grates. These difficulties, however, did not materialise to the extent anticipated, and problems in connection with the use of preheated air for combustion have been solved during the last few years, and it is safe to assert that the air preheater is now an auxiliary apparatus of special importance to boiler house efficiency and economy.

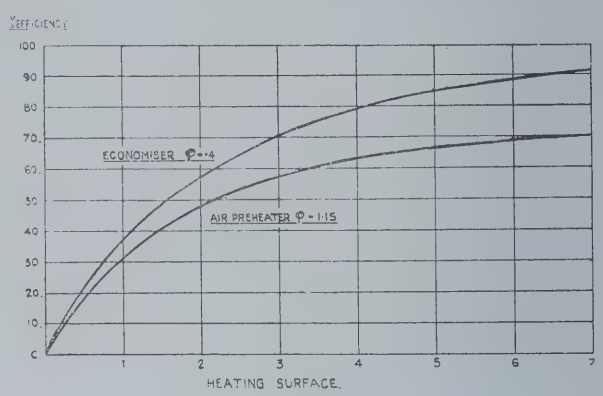


Fig. 1.

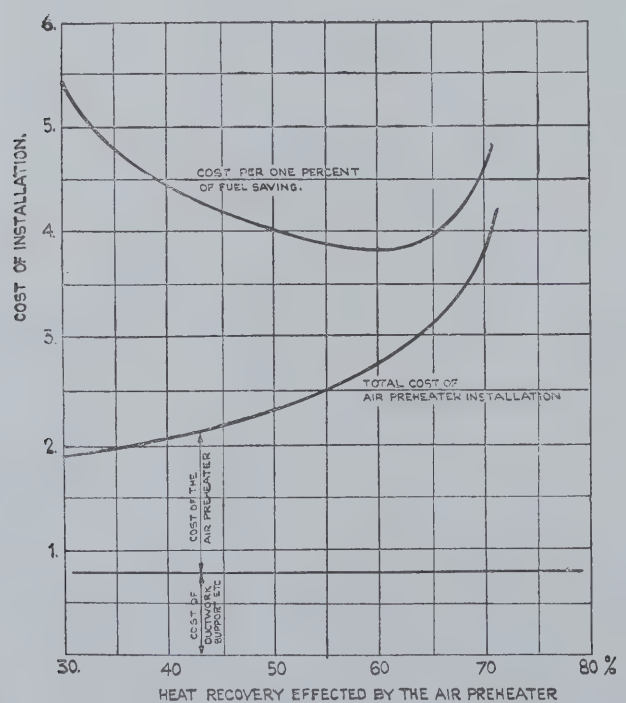


Fig. 2.

Economical efficiency.

From the point of view of heat recovery the economiser and the air preheater follow the same laws. Assuming that the heat transfer coefficient is the same in both cases the heating surface required for a certain efficiency would be as shewn in Fig. 1 for an economiser and air preheater respectively. The curves are drawn for a ratio between $\frac{\text{quantity of flue gases} \times \text{specific heat}}{\text{quantity of feed water} \times \text{specific heat}} = \varphi = 4$ for the economiser and similarly $\varphi = 1.15$ for the preheater.

The heating surface is considerably increased both in the case of the economiser and the air preheater when an efficiency of more than 50 to 60 per cent. is required. It is, therefore, clear that a combination of the two apparatus, in series, will give the smallest heating surface for a specified heat recovery.

This type of arrangement is becoming very common to-day. The economiser in which the heat is transferred to the feed water, is placed first and the air preheater in which the heat is transferred to a fluid of lower temperature, the atmospheric air, is placed last in the series.

It may be of interest to deal briefly with the question of the economical efficiency of the air preheater. The size of economiser in a modern plant with high feed water temperature is severely limited

and the economical efficiency of the preheater, considered in connection with the desirable final flue gas temperature has, therefore, a decisive influence on the exit flue gas temperature from the boiler. In Fig. 1 the air preheater efficiency is taken to be:—

$$\frac{\text{drop in flue gas temperature effected by the preheater}}{\text{temperature of entering flue gases—temperature of air entering preheater.}}$$

From this curve it would be expected that an efficiency of 45 to 50 per cent. would represent the economical optimum. Taking into account the total cost of an air preheater installation, it will, however, be found that the fixed charges for duct work, insulation, support, etc., represent a considerable sum, and that the preheater efficiency giving the best return on the capital invested is higher than may be expected.

In Fig. 2 the relative cost of a preheater installation designed for an efficiency ranging from 30 to 70 per cent. is given. Although the actual cost is not given the curves are based on the installation cost for a 60,000 lb. per hour boiler. The curve shewing the capital cost per one per cent. of saving effected by the preheater is of special interest. It will be seen that this does not follow the indications of Fig. 1, and that the most economical plant is obtained with a preheater of 55 to 65 per cent. efficiency.

If an air preheater efficiency of this extent is desirable from a heat economy point of view, it is clear that the combustion engineer must face the problem of using air for combustion of fairly high temperature. The question of safe working temperature is still very vague. Statements are frequently made that 250° F. or 350° F. is the absolute maximum which can be used for a certain type of stoker, but such statements cannot be accepted unless the specific conditions under which the stoker has to work

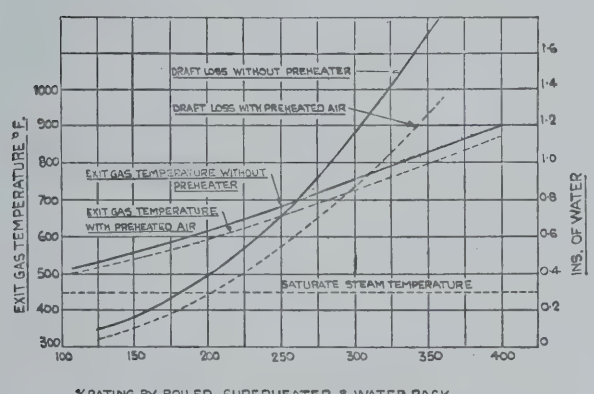

DRAFT LOSS WITHOUT PREHEATER
DRAFT LOSS WITH PREHEATED AIR
EXIT GAS TEMPERATURE WITHOUT PREHEATER
EXIT GAS TEMPERATURE WITH PREHEATED AIR
SATURATE STEAM TEMPERATURE
EXIT GAS TEMPERATURE °F.
INS. OF WATER
% RATING BY BOILER, SUPERHEATER & WATER BACK.

FIG. 3.

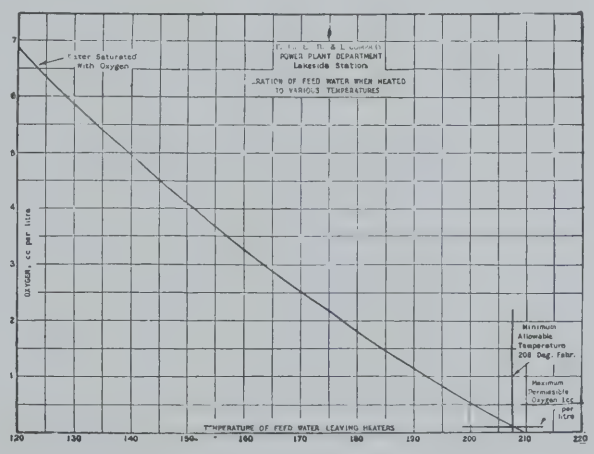

POWER PLANT DEPARTMENT
Lakeside Station
Minimum Allowable Temperature 208 Deg. Fahr.
TEMPERATURE OF FEED WATER LEAVING HEATERS

FIG. 4.

are given. Conditions in a boiler vary considerably. Some types of fuel give an easy fusing clinker, other types do not. In a combustion chamber of ample size the temperature conditions are more favourable than in the combustion chamber with high specific load. It is clear that, if highly preheated air is used, it is necessary to meet the new requirements, and it is also obvious that in the present state of engineering practice, there is no limitation from a physical point of view, either with regard to the preheater or the stoker.

Power stations are already being built where the feed water is heated by bled steam to a temperature close to the saturation temperature of the steam. The economiser must naturally be eliminated in such an installation and the air preheater must have a high heat recovery capacity in order to make a high boiler efficiency and high boiler rating possible. Air temperatures of 350° F. up to 600° F. may, therefore, be expected to be common practice in the near future, and the manufacturers of grates and furnaces will have to solve the problems arising from these high temperatures.

Furnace conditions.

The use of preheated air somewhat alters the thermal conditions of the combustion process and has a marked influence on the physical and chemical reactions in the furnace. Owing to increased furnace

temperature the boiler heating surface exposed to direct radiation will have to carry a greater load, and this is of advantage to the boiler capacity. The amount of heat, per square foot of heating surface, which can be transferred through direct radiation to the boiler heating surface is much larger than the heat transferred through convection in the latter part of the boiler.

To illustrate this a curve (Fig. 3) shewing the heat absorption of the water screen relative to the total heat absorption of a boiler is introduced. Although the heating surface of the water screen is very small compared with the total boiler heating surface, the evaporation is very much larger, per square foot. From a practical point of view, there is no limitation to the load which may be maintained on the tubes exposed to direct radiation, provided the construction of the boiler allows for rapid circulation of the water.

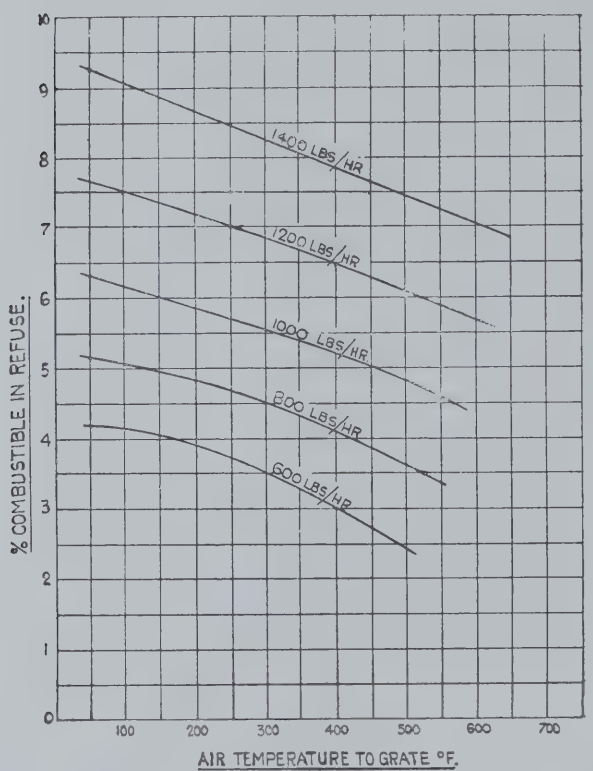


Fig. 5.

The main advantage of the air preheater is that by increasing the intensity of heat transfer through direct radiation the capacity of the boiler is increased. A larger heating surface exposed to direct radiation can be accommodated in the combustion chamber without detriment to the combustion process and the capacity of the grate. The rate of heat transfer through convection cannot be materially increased, and any increase obtained is purchased at the cost of increased draught losses due to the higher velocity required.

If full advantage is to be taken of preheated air it is clear that a larger heating surface should be arranged in the furnace, in which way no increase whatever, or a very small increase, in the furnace temperature may be obtained.

The type of boiler, however, now usual in power station practice will benefit to a large extent from the use of preheated air. An increased amount of heat will be absorbed in the furnace and a higher boiler rating can be maintained with the same exit flue gas temperature.

Fig. 4 illustrates the drop in flue gas temperature through a boiler with an air preheater in commission and with cold air for combustion. It is clear that if the temperature passing through the boiler can be reduced by use of preheated air it would be possible to cut out a considerable number of tubes in the latter part of the boiler.

Effect of air preheater on boiler efficiency.

The question has frequently been raised as to the effect the preheater has on the boiler efficiency. As shewn in Fig. 4 the exit flue gas temperature from the boiler is lower at the same rating with preheated air. If an air preheater be installed fn connection with a boiler, it is, therefore, clear that all the heat recovered and returned to the boiler is transferred to the boiler, due to the more intense radiation from the flame and the fuel bed.

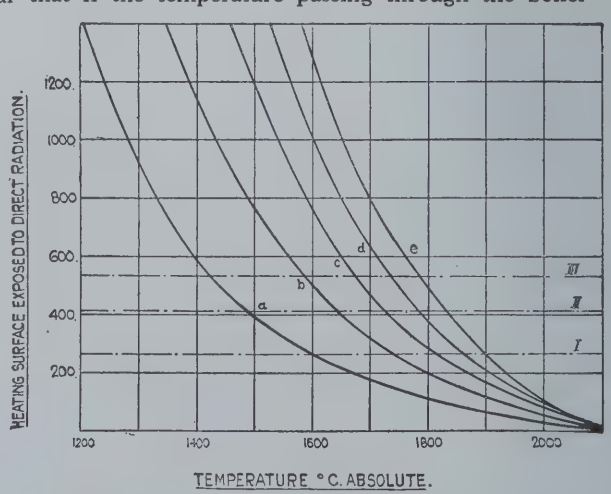


Fig. 6.

It has been said that the increase in efficiency effected by the preheater is equal to the heat recovered multiplied by the boiler efficiency. This statement is evidently based on the misconception that the heat introduced with the air for combustion should be treated in the same way as the heat introduced to the furnace with the fuel. At the same CO_2 content it is, however, clear that the same flue gas quantity is obtained whether preheated air is used or not, and that the increased intensity of combustion not only transfers all the heat introduced with the air at 100 per cent. efficiency, but also effects a slight drop in exit temperature from the boiler. In most instances with a normal boiler this reduction in temperature is, however, fairly small, and cannot be taken into account when the boiler efficiency is estimated.

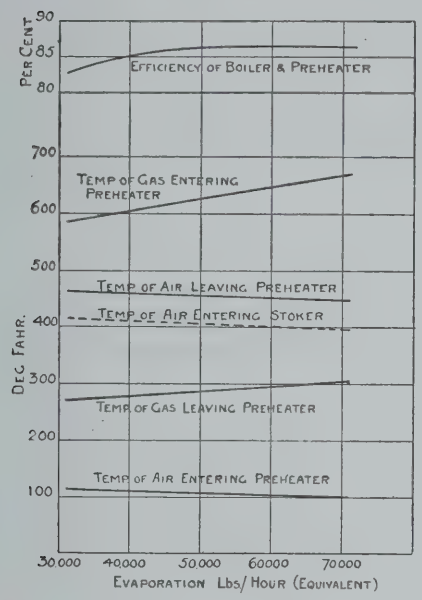


FIG. 7.

The effect of the air preheater can, therefore, with safety be calculated to be equal to the sensible heat recovered from the flue gases. The calculation of the heat recovery is easily made when the type of fuel and the reduction in flue gas temperature is known. The following equation gives the recovery in per cent.:—

$$S = Q_g \times C_{pmg} \times (T_1 - T_2) \times \frac{100}{C}$$

where S = Sensible heat per cent.; Q_g = Quantity of gas per lb. of fuel; C_{mg} = Mean specific heat of the gas; T_1 = Temperature of gas entering preheater; T_2 = Temperature of gas leaving preheater; and C = Calorific value of the fuel B.Th.U.'s/lb.

or approximately $$S = C \times \frac{T_1 - T_2}{CO_2} \times 100$$

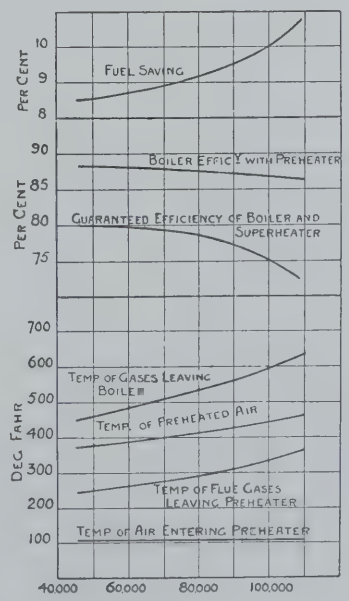
where C = constant, equal to about .36 for bituminous coal; and CO_2 = per cent. CO_2 in the flue gases.

Preheated air and the combustion process.

It has already been stated that preheated air has a certain influence on the combustion process. This is specially marked in the combustion of the coke residue on the grate. At higher temperature and higher velocity of the air through the fuel bed there is a greater affinity between the coke and the oxygen. This reaction, under normal conditions, is very slow and the capacity of the chain grate, for instance, is frequently limited by the slow combustion of the coke. The result is that when preheated air is used it is invariably found that the combustible in the refuse is lower.

Extensive tests to find the effect of preheated air and the combustible in the refuse have been carried out at the Chester Station of the Philadelphia Electric Company, U.S.A., and Fig. 5 is a curve reproduced from the "Prime Movers Committee Report," 1925-26, which shews that with high air temperatures there is a very definite decrease in the combustible in the refuse.

In boiler furnaces equipped with water cooled walls the low furnace temperature has an adverse effect on the combustion process, but this is comparatively eliminated by the use of preheated air. It has sometimes been stated that with preheated air it is possible to maintain a higher CO_2 content in the furnace. This increase, however, with refractory furnaces, would not be appreciable.



Stokers.

Reference has been made to the fact that temperatures of 350° F. to 600° F. will be necessary to work with in the modern boiler house with extensive feed water heating. It will, therefore, be of interest to consider briefly the difficulties which may be encountered when highly preheated air is used.

At the temperature mentioned the mechanical working of the stoker can be safely made provided sufficient clearance for extra expansion is allowed, and that this is an easy matter is indicated by the fact that makers of the retort type stokers are already in the position to offer grates suitable to work with temperatures of 550—600° F. Plants of this description have been operating for several years in the United States.

Chain grate manufacturers are, however, more reluctant to accept these high temperatures, probably due to the fact that the grate is relatively unprotected from the heat in the furnace, and that the fusing or melting clinker may break up the stoker. Finally, the troubles of rapid deterioration of the links due to high sulphur content of the coal in the form of pyrites may be aggravated if preheated air is used. These troubles, however, may be avoided if effective cooling of the grate itself is arranged and by giving adequate volume to the furnace.

In some cases the chains of the grate have been cooled on the return passage by water-cooled drums at the rear of the stoker, and this has given very satisfactory results. In cases where 300° F. air temperature gave trouble before the cooling arrangement was installed it is now possible to work with 450° F.

The most effective way of keeping down the furnace temperature and thus eliminating one of the most important causes of trouble is to arrange the heating surface in such a way that a large amount of heat can be absorbed by direct radiation, and to provide for sufficient combustion chamber to keep the furnace rating within reasonable limits. The influence of the furnace rating and the size of the heating surface exposed to direct radiation is clearly shewn in Fig. 6.

Where water-cooled walls can be installed no difficulties exist with highly preheated air, but the installation of these may not be economically possible for smaller boilers. If boilers with refractory furnace walls are equipped with chain grates it is, however, possible to cut down the arch considerably, since the ignition on the grate takes place at an earlier stage.

When preheated air was first introduced in boiler house practice, operating conditions and difficulties were aggravated by the low and long arches extending for more than 60 per cent. of the grate, and running parallel with the fuel bed. It is now appreciated that with preheated air the arches can be cut down considerably, and thus more heat released from the grate, and the furnace temperature kept down by proper arrangement of the heating surface. If proper care be taken in the design of the arches and stokers and adequate furnace volume is provided for, no trouble need be expected with air temperatures as high as 500° F., and practical experience with various types of installations over a period of several years has conclusively proved this fact.

In Fig. 6 are shewn curves of test results from a Stirling boiler equipped with preheater but no economiser. The temperature of the air for combustion entering the wind boxes is about 400° F. over the whole range of load. The type of fuel used is South Midlands slack, and no trouble whatever has been experienced with the furnace lining or chain grates as a result of the high air temperature.

Fig. 7 embodies similar curves from a boiler equipped with a preheater but no economiser and arranged for oil firing. It is most noteworthy that the efficiency curve both for fuel oil and for coal is very flat. This depends on various reasons, such as increased furnace capacity due to more rapid ignition and more complete combustion, less combustible in the refuse at high loads with the chain grate stoker, and a constant and low temperature of the fluid to which the heat is transferred, the air entering the preheater.

In short, it may be said that the air preheater enables a reduction to be made in the capital cost of the boiler unit and to increase the efficiency at high boiler ratings. Air preheating and the preheaters themselves have passed out of the experiment stage, and there is now no valid reason why engineers should view the installation of preheaters with apprehension.

PULVERISED FUEL.

PRACTICE AND PROGRESS IN PULVERISED FUEL FIRING FOR STEAM RAISING

By F. H. Rosencrants, B.Sc., A.S.M.E.

A great deal of prominence has been given to the application of pulverised fuel to the firing of boiler furnaces through the large number of installations made in the past few years. It may still be rated, however, as a new but rapidly developing industry. Though there were several plants in operation using pulverised fuel at the time when the Oneida Street plant of the Milwaukee Electric Railway and Light Company went into operation, the publicity given to this installation starting from a date early in 1920, and to the Lakeside Station of the same company built shortly afterwards, properly marks the beginning of any widespread interest in the subject on the part of engineers. The larger part of this interest manifested itself in adverse criticism, but the result proved no exception to the saying that, " It is much better to be criticised than to be ignored." Several installations followed during the years 1921 to 1923, among which the River Rouge Station of the Ford Motor Company, Detroit, the Cahokia Station of the Union Electric Light & Power Company, St. Louis, and one large boiler at the Springdale plant of the West Penn. Power Company, Pittsburgh, were, perhaps, the most prominent.

By virtue of these installations interest was maintained at a high pitch, though progress was slow and most of the comments continued to take the form of criticism. It has been during the last four years that by far the larger number of pulverised fuel-fired boiler installations now operating have been built. Experience accumulated slowly during the first few years and the knowledge gained therefrom was shared by but a very limited number of engineers of position and influence. It is only in the last two or three years that the accumulation of knowledge, born of experience, has become sufficiently diffused to enable any considerable body of competent thought to be brought to bear upon the problem. The same period, in consequence, has given rise to a large volume of ideas—sound and otherwise—for the improvement of pulverised fuel equipment and plant design. Without further contribution it will take some time to sort the relatively sma'l amount of wheat from the large amount of chaff and, in the meantime, the production of new ideas continues at an increasing rate. The ultimate result, of course, will represent progress—attained at a high cost perhaps—but in the end worth the price. It is not a period for discouragement, but certainly one for the exercise of discretion.

The possibility of fame by the attainment of high efficiency has been all but exhausted. Authentic gross efficiencies of 87 to 89 per cent. are being obtained in several instances, a figure which leaves but little room for improvement. There is still scope, however, for inventive genius in connection with refinements in design of equipment and plant layout, with the object of rendering plants more reliable and less costly to construct, operate and maintain. Such improvements are constantly in process, but the field is still fertile.

That the problems confronted are different in different countries, as a result of the rather wide variation in coal characteristics, a careful student of conditions existing in England, America and on the Continent will come to realise. In the United States the large majority of plants utilise coals of high heat value having high-volatile, low-ash and low-moisture contents. True, there are notable exceptions, but they *are* exceptions. In Germany a large proportion of the coals utilised for steaming purposes are low in volatile matter, in addition to which the problem of handling lignite is receiving a great deal of attention. In England the harder quality and the high ash and moisture content of a large proportion of the coals utilised present problems for special consideration.

The position of pulverised fuel firing in relation to stoker firing continues debatable and unstable. The efficiencies and flexibility attained with pulverised fuel from the first has been a source of inspiration to stoker designers, with the result that big strides have been made in the improvement of this class of combustion equipment. Greatly increased combustion rates per square foot of grate surface have been realised; the control of air supply has been greatly improved ; the development of larger sizes has been successfully accomplished, though with increasing size nearly every feature of the design becomes more

difficult. Expansion, heavy loads over long spans, proper air distribution and control are among the problems which increase with the size of units, and at best the breakdown hazard increases with the multiplicity of parts in the furnace.

Engineers are rapidly realising, however, that the stoker has been perfected to such a point that it is finding its old home furnace an inadequate place in which to reside. In the days when engineers were content to burn 20 to 25 pounds of coal per square foot of grate, with cold air supplied in sufficient excess to give a CO_2 content of 9 to 11 per cent., furnace walls, arches and grates gave but little cause for concern. Present-day conditions, however, require combustion rates of 40 to 50 pounds of coal per square foot, with air supplied under forced draught at a temperature of anything up to 550 deg. F., and with the excess reduced to a point represented by a CO_2 content in the furnace of 13 to 16 per cent. The result is furnace troubles which are, at the moment, becoming acute. In the solution of the problem water cooling of the refractories, both as applying to side and rear walls and to arches, is receiving the consideration of engineers. In the United States many boilers are now equipped with water-cooled walls and practically all of the larger installations under construction include water cooling of some form and to some extent. Up to the moment activity has not become so intense in England, though a few furnaces with water-cooled walls are operating, and contracts have been placed for a small number in addition. It is a development which is sure to make progress—and at an accelerated pace.

With the rapidity with which progress is taking place, both as applying to pulverised fuel firing and stoker firing, their relative positions can be nothing other than unstable. The competition between them at the moment is good for the health of both, and the position offers room for a considerable amount of unprejudiced debate. Such, however, as are fully informed and unprejudiced will concede a field for each. Expressed in broad terms—small boilers should be equipped with stokers and large boilers with pulverised fuel. The greater the number of boilers involved, the stronger is the position for pulverised fuel, and *vice versa*. Circumstances alter cases, however, and at the present time circumstances are such that he would be bold indeed who would attempt to draw closely the lines limiting the field of either.

SYSTEM OF PULVERISED FUEL FIRING.

Two systems as applied to boiler plants have become well established, namely, the "Bin and Feeder" system (sometimes referred to as the "Central Grinding" system) and the "Direct Fired" system (sometimes referred to as the "Unit" system).

The bin and feeder system is characterised by a pulveriser or pulverisers which deliver their product to a pulverised coal storage bin, from which, through the medium of suitable feeders, a regulated supply of coal is fed to the furnace through burners so applied as to proportion and mix the coal with the required air for combustion. In the early plants the pulverisers were almost invariably grouped together, usually in a separate building. There the total requirements of coal for the entire boiler plant were pulverised and later distributed to the individual bins supplying the several boilers. Hence the name—Central Grinding system.

There followed plants so arranged that the pulverisers, instead of being grouped together, were more closely associated with the boiler units, and the pulverised product delivered direct to the individual boiler bins. This departure upset the significance of the designation Central Grinding system, and it was often referred to as the Storage system. It is only recently that this system has become known as the Bin and Feeder system.

The direct-fired system is characterised by a pulveriser or pulverisers which, supplied with a regulated feed of raw or coarse coal, deliver the pulverised product direct to the furnace through suitable burners. Here again, the designation supersedes the previous inadequate title "Unit System" applied in the earlier period of development, when one small pulveriser supplied one comparatively small boiler. Reliability and the increasing size of boilers soon demanded a multiplicity of pulverisers. Furthermore, it is not impossible, or indeed an unknown occurrence, to apply the Bin and Feeder system on a unit basis, *i.e.*, one pulveriser with its corresponding bin and feeders per boiler unit. The designation direct-fired system is sufficiently descriptive to avoid any possibility of confusion and broad enough to cover the system to which it applies in all its modifications. As such, it appears to be all that could be desired.

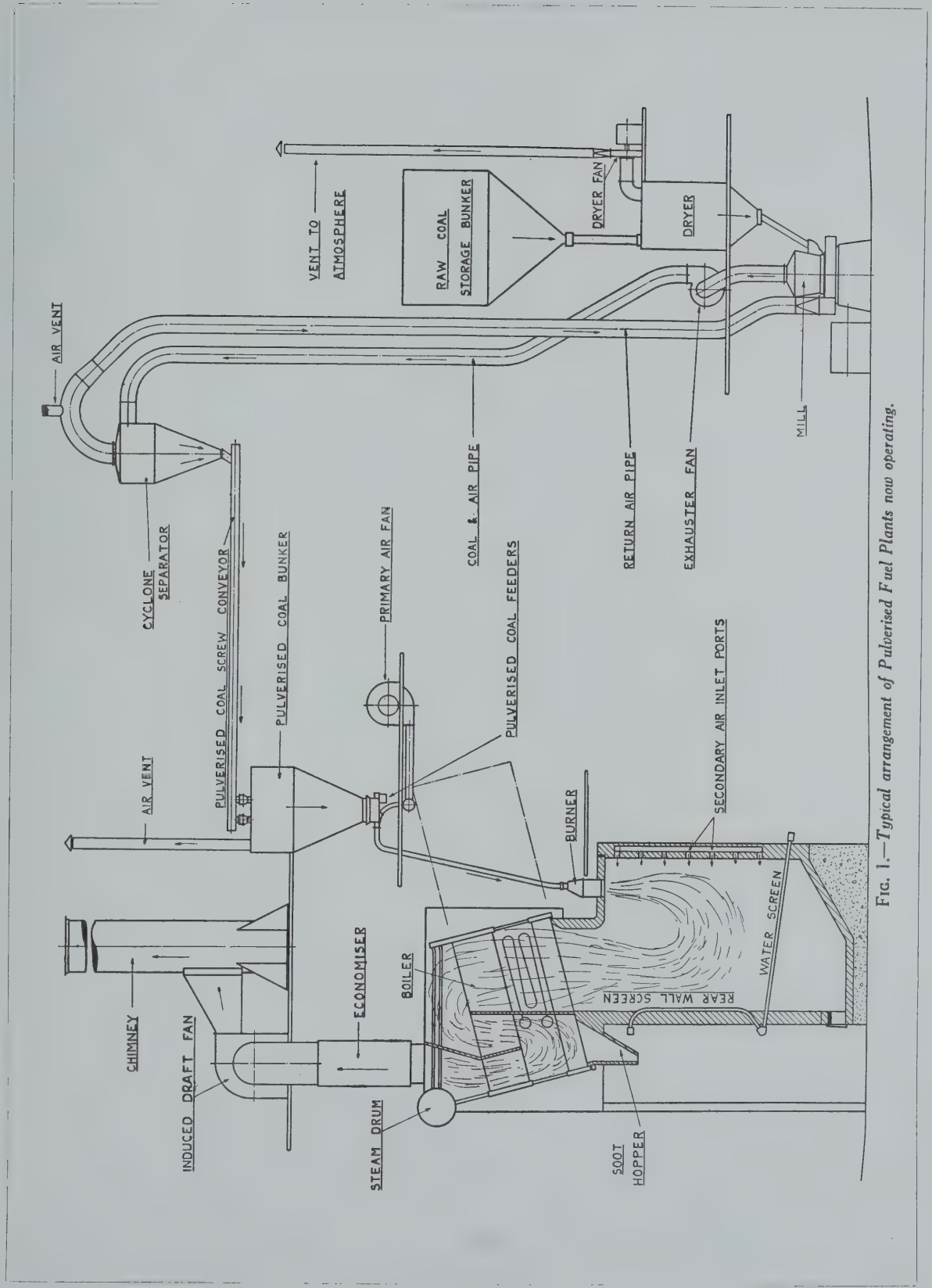
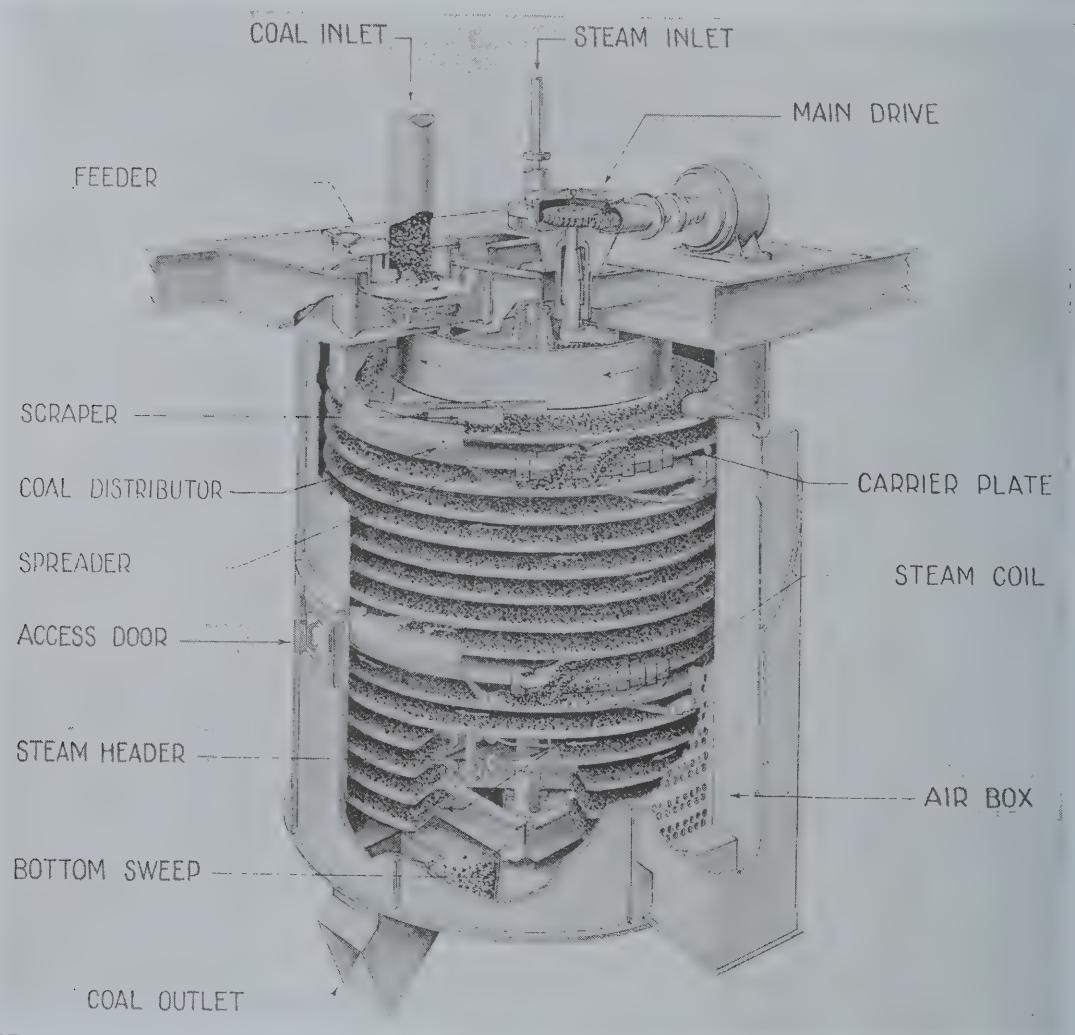


FIG. 1.—*Typical arrangement of Pulverised Fuel Plants now operating.*

THE BIN AND FEEDER SYSTEM.

An arrangement of plant typical of many now operating, is indicated in Fig. 1. Reference to this in connection with the discussion which follows of the various elements entering into the system, will make it sufficiently clear to obviate any necessity at this point for entering upon lengthy explanations. We therefore proceed to a discussion of the various elements, making no effort to limit the discussion to the type or make of equipment as shown in Fig. 1, but rather endeavouring to expand sufficiently to give a comprehensive view of the field. There is little about the raw or coarse coal-handling plant, as applying to pulverised fuel, to warrant lengthy comment. It differs only in that for the greatest satisfaction



[*Patented*]

FIG. 2.—*Sectional View of Steam-heated Dryer.*

in handling the coal through the system, the coal should be screened through about a two-inch mesh, and it should be passed over a magnetic separator to remove the iron which finds its way from various sources into the coal supply. While both are advisable, neither is essential. We therefore pass on to the outlet from the raw coal bunkers and start our discussion with the subject of drying.

Drying and dryers.

To utilise wet coal successfully it becomes necessary to dry it to a point such that it may be efficiently handled through the various elements of the system. To the extent that we so design equipment that it will handle wet fuel, we lessen the necessity for drying. With a system of elements so arranged

that the coal passes through them in series, however, that element which has the minimum moisture-handling limit determines the point to which the coal must be dried. It becomes apparent, therefore, that if we would reduce our drying problem we should direct our attention to the improvement of those elements having a low moisture-handling limit, in order that this limit may be raised to equal that of the best element in the system. Our ultimate object should be to so perfect equipment in this respect that no drying is necessary. Such a goal does not appear impossible for the large majority of cases.

Theoretically, no heat loss arises from the drying process. The moisture which is in the coal as received must be evaporated either in a dryer or in the furnace, and approximately the same amount of heat will be required in either case. Actually, a loss of heat is usually associated with drying prior to feeding the coal to the furnace, due to the inefficient means of applying heat in dryers, as compared with the efficiency of heat application in the furnace. In considering the heat required to dry coal in a dryer, however, it is important that we do not get a distorted view of magnitude by failing to consider the amount of heat which would be absorbed in the furnace by the moisture in the coal if it were not removed by pre-drying.

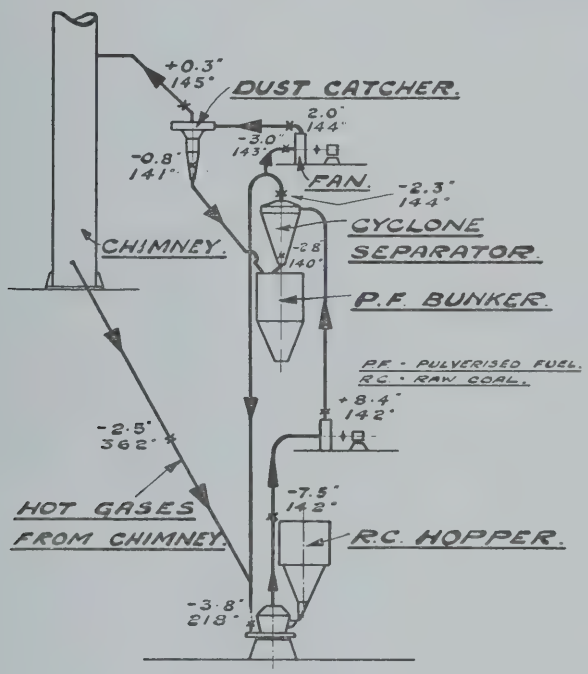
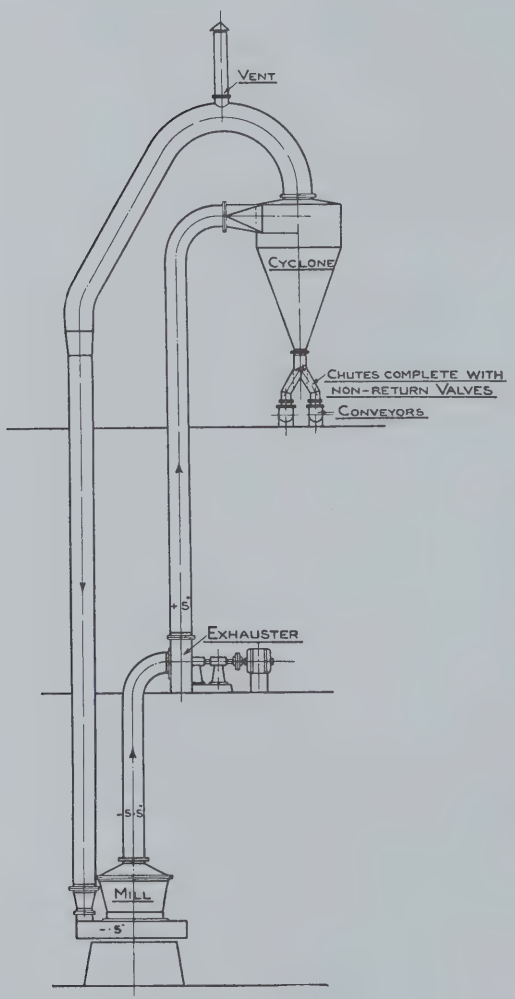


FIG. 3.—*Sectional View of Installation using Flue Gas for Drying.*

Two forms of moisture are recognised, commonly designated as free moisture and inherent, or hygroscopic, moisture. The former is that which the coal gives up when exposed to atmospheric air at atmospheric temperature. The latter is that which is retained after continued exposure to atmospheric air and imparts no sensation of wetness. It is well established that the harmful influence of moisture on the behaviour of coal in the various elements of a pulverised fuel plant may be almost wholly charged to free moisture. It is also well established that it is not usually the uniformly distributed moisture which causes difficulty, but rather a concentration of moisture resulting from condensation at points where the pulverised product comes in contact with improperly insulated surfaces. It follows, therefore, that the moisture content of a coal expressed as a total gives no indication as to the necessity for drying, or the extent of drying required. Some high-grade bituminous coals carrying as much as 6 to 8 per cent. of total moisture may require drying in order to be handled with any degree of satisfaction. There are deposits of lignite which may be handled with complete satisfaction, with as much as 30 per cent. moisture. To state intelligently the limiting percentage of moisture which may be handled without drying requires experience with the coal under consideration, or with coal closely approaching it in characteristics. In any event, the limit is being raised continuously by improvements in equipment and in plant design.

Until a very few years ago, the best known form of dryer was the horizontal indirect-fired rotary dryer, of which there are many in service for drying coal and other materials. Even to-day, its ability to function and its capacity for drying are better established than is the case with any other form. Indeed, the most conspicuous feature in the drying field is the number of dryers which have been developed and proved failures. Unfortunately, however, the horizontal indirect-fired rotary dryer, though an acknowledged success as an effective dryer, is sufficiently handicapped by disadvantages which might be discussed under the headings—space requirements, extra coal-handling equipment and dry coal bunkers required, attendance, cost, efficiency and dust nuisance—that it has never become popular for power-station practice, in spite of disappointments experienced with other forms.

It was early recognised that a vertical form of dryer through which the coal would flow by gravity in response to mill demand was most desirable. Such a unit eliminates the necessity for dry coal-handling equipment and storage, with consequent danger of bunker fires; no extra operating labour is required, and building space is provided by the addition of a few feet in height. The advantage of the absence of moving parts was also recognised. The heat required for the drying process with this form of dryer was supplied through the medium of hot flue gases after they had left the heat-absorbing surfaces of the steam-generating unit, or steam at moderate pressure, or a combination of both. Though a considerable number of dryers answering to the above general description have been installed and are operating, their history



[*Patented*] FIG. 4.

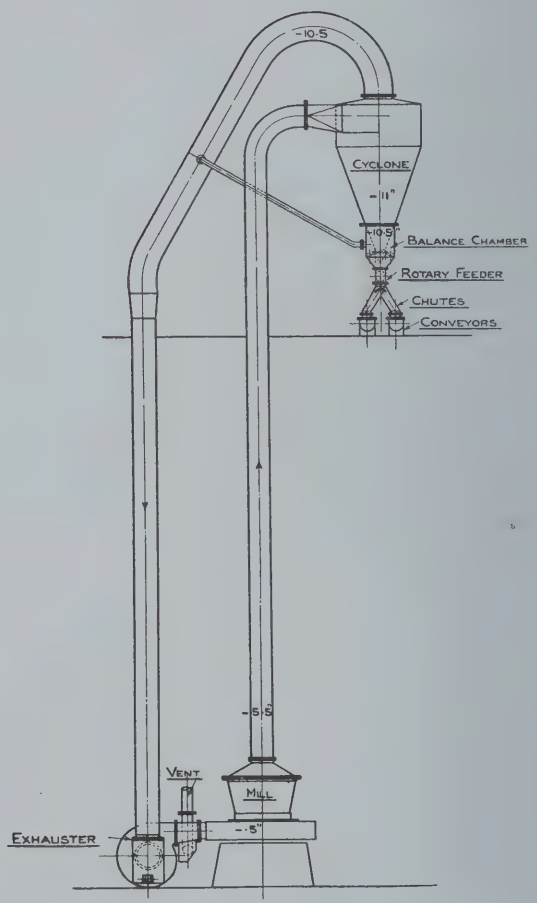


FIG. 7.

is not a happy one. Inability to obtain a uniformly distributed flow of gas in the required volume through the coal bed; failure to obtain a uniform flow of coal over the full cross-section of the coal stream, with consequent local fires due to overheating; dust nuisance, resulting from the fine coal picked up by the gas or air in its passage through the coal bed, are some of the difficulties experienced. With a nutty coal, reasonably free from fines and sufficiently dry to enable it to flow freely, the dryers operate with fair satisfaction. With very fine wet coal, however, they are a total failure. In other words, their ability to function varies inversely with the need of it. As a result, their utility is reduced to a very narrow field of application.

To overcome the obvious limitations of the dryers above discussed, recent efforts have been devoted to the development of steam-heated dryers retaining the advantage of gravity flow but supplementing it with positive propelling equipment for ensuring a uniform flow of coal through the unit. Fig. 2 is typical of this form. A further advantage is that the air circulation for carrying away the vapour does not pass through the coal, with the result that the dust nuisance present with the previous forms is diminished to the point of elimination. The functioning of this form of unit promises well for its complete success. It has the disadvantage, however, of being expensive.

It may be said, with confidence, that the drying problem is on the eve of solution. It may also be asserted that the steady progress in the improvements taking place in the design of other elements of the system, by virtue of which the moisture limit with which the system will deal satisfactorily is raised, is such that by the time dryers have been perfected they will be no longer required, other than in exceptional cases.

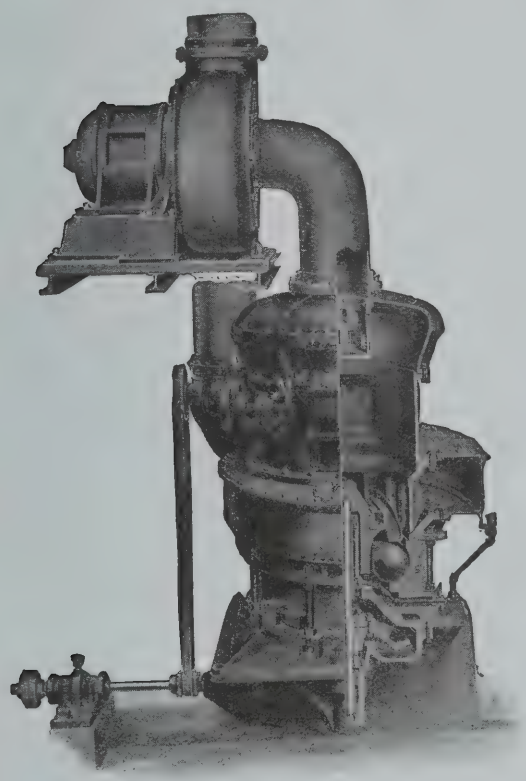


FIG. 5.—*Fuller Pulverising Mill.*

Before leaving the subject, drying by means of the admission of hot air or gas into the pulveriser circuit merits mention. This system involves the admission of hot air from the air preheater or flue gas from the boiler outlet into the return air circuit just before it enters the pulveriser. The intimacy of contact between the air or gas and the coal in the mill results in very rapid drying. To the extent that air or gas is admitted into the mill, it must be taken out at some other point. This is the disadvantage of the system. If hot air is used, with proper precautions it may be blown into the furnace. If flue gas is used, it may be discharged to the furnace, or perhaps to the chimney.

Fig. 3, is a diagram of an actual installation using flue gas for drying, with test values of temperature, degrees F. and pressures (plus or minus) in inches water at various points in the system. The following set of figures apply to the same test:—

Duration of test	Hrs. 3, mins. 20.
Throughput	4.29 tons/hr.
Quantity of gases entering mill ...	9,930 cu. ft./min.
Quantity of hot gases admitted to return gas-pipe...	4,500 cu. ft./min.

ANALYSIS OF SAMPLES TAKEN.

Raw Coal—

Moisture.

Free	4.11%
Hyg.	5.33%
Total	9.44%
Fixed Carbon as received...	52.97%
Hydrogen	3.18%
Ash	22.52%

Pulverised Coal—

Moisture.

Free	0.00%
Hyg.	4.92%
Total	4.92%
Removed ...	4.52%

Screening Cyclone Sample.

Over 60 mesh	5.41%
Through 60 mesh	94.59%
Through 100 mesh	87.78%
Through 200 mesh	67.23%

Dust-catcher Sample.

Over 60 mesh	1.23%
Through 60 mesh	98.77%
Through 100 mesh	94.90%
Through 200 mesh	92.11%

Pulverising and pulverisers.

The pulverisation of granular materials was a very old art long before the present rapidly growing movement in the application of pulverised fuel to the firing of boiler furnaces.

As is well known, the pulverisation of coal has been well established in the cement industry for many years. Hence, the sporadic attempts over the past thirty or forty years to apply pulverised fuel to boiler furnaces failed, not by reason of the absence of successful pulverising equipment, but rather by improper application and furnace design.

The large majority of installations in the cement industry used pulverisers of the screen-separation type. In this form of pulveriser the coal is continually being thrown at an angle against screens having about 16 to 20 meshes to the linear inch. That which has been pulverised to the desired degree of fineness passes through the screen, assisted by a current of air supplied by a fan or fans incorporated in the pulverising unit. The pulverised product runs from the unit by gravity and is delivered by some form of transporting and elevating equipment to storage bins.

Some pulverisers of the screen-separation type are in use in boiler plants and they have the advantage of low power consumption. They possess, however, the inherent disadvantage that the coal must be dried down to about 1.5 per cent. moisture, in order to avoid plugging the openings in the screen. Further, the screen becomes damaged and wears out at a sufficiently rapid rate to form a source of annoyance and expense. The whole of the milling system is under a slight pressure, so that any leakage results in an outward flow of a mixture of coal dust and air into the pulverising room. These disadvantages have been sufficient to discourage their extensive use for power station work.

Screen separation was superseded by air separation and the scheme is adopted by all leading manufacturers of pulverising equipment, as applied to the Bin and Feeder system. The arrangement of plant shown in Figs. 1 and 4 is typical of the large majority of plants operating on this system to-day. The air pressures (plus and minus) indicated in inches water on Fig. 4 are typical only. As will be observed, the air flows in a closed circuit, the only interchange of air taking place being that which leaks into those parts under vacuum and displaces a corresponding amount which escapes through the vent. The chief source of leakage is through the coal feed. The total leakage, however, is but a small volume per minute.

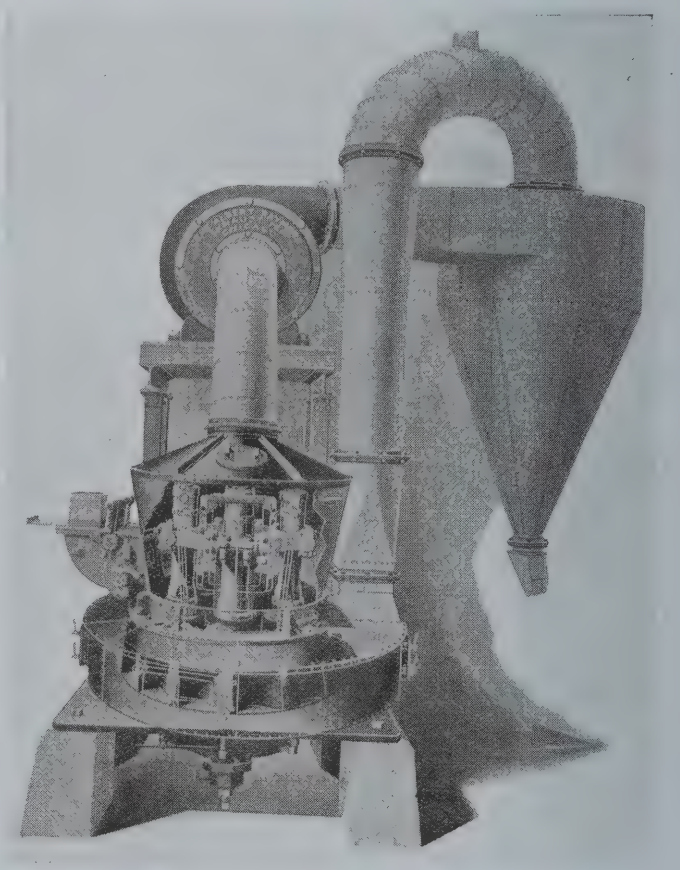


FIG. 6.—*Sectional View of the Raymond Mill.*

The pulverisers shown in Figs. 5 and 6 have found wide application in power-station practice. In both, the grinding action is much the same, in that it takes place between metal surfaces brought firmly into contact, through the action of centrifugal force originating from the rotation of the set of balls, in the

one instance, and of the suspended rollers in the other, about the central axis. The balls and rolls and the rings against which they bear through the action of centrifugal force are the parts most subject to wear, and hence are made renewable.

Separation of the finished product from material in process is brought about by the air current which, entering the grinding chamber through a series of openings extending completely around it, passes up through the coal in process and carries away the finished product in suspension. The mixture of coal and air leaves the pipe connected to the top of the pulveriser and passes through the exhauster and on to the cyclone separator, from which the coal dust is discharged at the bottom. The air returns again to the pulveriser, thus completing the circuit.

Pulverisers of this general description are essentially constant load machines. The three variable factors are pulveriser speed, exhauster speed and coal feed. As normally operated, however, pulveriser and exhauster speeds are kept constant and the coal feed adjusted to give maximum output.

Ball mills of the conical or tubular type thus far have not become popular for pulverising coal. The inherent inability of this type of mill to handle moisture is perhaps the chief cause, though the noise associated with their operation is also a contributing factor. The energy consumption per ton of coal pulverised is not prohibitive though high, and the maintenance cost is lower than for any other type. For hard abrasive fuel, such as anthracite coal or coke, they are superior to all other pulverisers.

The principal points to receive consideration in the selection of a pulveriser are :—Capacity of unit, energy consumption per ton of coal pulverised to a specified fineness as applying to a coal of specified characteristics and moisture content, maintenance, noise, etc. All of these, with the exception of noise, vary with the character of the coal and its ash and moisture content. When we consider the widely varying characteristics of coal from lignite to anthracite, as well as the variation in ash and moisture content encountered with each grade, it is not surprising that guarantees received in response to enquiries vary over a wide range. Actual experience covering the coal specified is too often not to hand, in the absence of which the manufacturer must make deductions as best he can.

Wear is a factor which, unfortunately, is associated with any grinding operation. It is intimately associated with the pulverisation of coal, and varies widely with the character of the coal and its ash content. Generally speaking, it increases with the hardness of the coal, percentage of ash and moisture content. The presence of abrasives in the coal, of which iron-pyrites is perhaps the most prevalent, has a large influence. Hard anthracite coal probably should not be ground in other than a ball mill of the tubular or conical type. Metallurgical coke effects an amount of wear approaching the prohibitive in any type of mill.

The problem is not how to prevent wear, but how to accept it with the minimum expense. The solution lies in a careful selection of materials as applying to wearing parts, the proper proportioning of wearing parts, design details permitting wearing parts to be readily and cheaply renewed, and an arrangement of associated parts so that the connecting pipe-work may be as straight and short as possible. Chilled cast iron, heat-treated alloy steel and manganese steel, thus far, have proved to be the best materials for those parts subjected to intense wear, and ordinary mild steel of suitable thickness for those parts such as straight pipes, etc., which are subjected to wear of lesser intensity. Pipe bends between the mill and cyclone should be avoided wherever possible, but where necessary should be made of cast iron, heavy gauge plate or steel pipe, cement lined. Cyclones should be lined throughout with renewable plates or cement. Exhausters should be on the air side of the circuit to avoid the severe wear on the impeller which takes place when the exhauster handles the mixture of coal and air with the plant arranged as in Fig. 4. Fig. 7 is a modified arrangement with the exhauster properly located and is typical of the arrangement adopted by the writer for all plants designed since early in 1926.

Aside from the advantage of avoiding wear on the exhauster impeller, the arrangement shown in Fig. 7 has further advantages. It places all parts of the system, except the short length of pipe between the exhauster and mill, under a pressure below that of the surrounding atmosphere, with the result that any leak which takes place admits air into the system which ultimately finds its way out through the vent rather than permit coal-laden air to be discharged into the pulverising room. It permits advantage to be taken of the centrifugal separation of coal dust and air which takes place in the exhauster in providing a coal-free air at the vent. By virtue of the energy delivered to the exhauster, approximately 50 per cent.

of which is converted into heat and delivered to the air handled, the temperature of the return air is raised and the trouble from condensation minimised.

Condensation of moisture in the pulveriser circuit is a source of annoyance, the prevention of which merits consideration. The air circulating in the mill system becomes almost immediately saturated with moisture absorbed from the coal. The actual amount of moisture taken up is influenced by the rise in the temperature resulting from the pulverising effort. All the energy applied in the process is converted into heat, the immediate effect of which is to increase the temperature of the air and coal in the system. This heat is ultimately dissipated through the discharge of the pulverised product at a temperature higher than that of the raw coal entering; through the vent air escaping at a higher temperature than that of the air leaking into the system; through the heat contained in the evaporated moisture carried out of the system with the pulverised coal and the vent air; but largely, in the closed system, by radiation from the mill, piping and cyclone surfaces. The temperature of these surfaces will rise to such a point above room temperature that equilibrium will be established between the amount of heat received through the conversion of energy and that radiated into the atmosphere.

The temperature is highest at the mill outlet (or at the exhauster outlet if the system is arranged as in Fig. 4). From this point on, cooling by radiation takes place. Immediately the temperature in the system falls below the dew-point, precipitation of moisture takes place. In the coal and air pipe and in the cyclone, moisture so precipitated is reabsorbed by the pulverised coal and leaves the system uniformly distributed through it. Temperature reduction and condensation continue in the return air pipe. The precipitated moisture is absorbed by the very limited amount of coal dust present, which becomes saturated and deposits on the interior surface of the pipe, and in the return air chamber of the pulveriser.

To insulate the entire system results in the temperature of the whole system being raised to such a point that by virtue of the increased temperature differential, the same amount of heat penetrates the insulation and is radiated to the atmosphere as before. Hence, the insulation serves no useful purpose. We may insulate the return air pipe from cyclone to mill, however, with advantage, leaving the rest of the system bare to radiate the heat received at the minimum possible temperature. As a result the temperature of the system is raised but little above that of an entirely uninsulated system; the insulation of the return air pipe effectively limits temperature reduction to a minimum, and condensation and its consequent annoyance is largely, if not wholly, eliminated.

If operated on the open system, the whole of it should be insulated, as the heat received will be carried away by the constant circulation of air into and out of the system.

Having correctly installed the pulverising units, their proper operation is of prime importance in securing low energy consumption, high output and long life of wearing parts. The most important factor in this respect is to keep the pulveriser properly loaded. Underloading is an all too frequent offence. The differential draught as measured between mill inlet and outlet by a " U " tube water gauge gives the proper indication of loading, since it shows the resistance of the coal bed in the mill to air flow. A fixed reading of this gauge indicates a definite amount of coal in the pulveriser. Hand control of the mill feed is a possibility, but automatic control governed by the differential draught across the pulveriser should form a part of every pulverising unit. Lubrication, periodical inspection and renewal of wearing parts are also important, and the manufacturer's instructions on these points should be carefully carried out.

Pulverised fuel transport and transporters.

As has been already indicated, coal may be pulverised in intimate association with the boiler units, or it may be pulverised in a separate building isolated from the boilers. In the latter case, some form of transport for the pulverised product to the bins serving the boiler units is essential; in the former case, it is desirable to the extent of making the product of any pulveriser available to any boiler unit.

Transport systems for pulverised fuel are of two general classes, namely, air transport and mechanical transport. Two forms of air transport, both using compressed air as the carrying and propelling medium, are in use, namely, the intermittent or " shooting " system, and the continuous or " pump " system.

For power-station service the shooting system is but little used. It consists primarily of an air-tight tank, fitted with proper air and coal connections, which is filled with pulverised fuel from the

pulveriser or from an intermediate storage bin, following which compressed air is applied and the complete charge blown through a connecting pipe-line to a bin at the point of consumption. In addition to the compressed air pressure behind the coal, a certain amount of compressed air must be injected into the coal stream at the point where it leaves the tank, to give it the necessary fluid condition to make it flow freely. The chief factors which have prevented this system from becoming popular for power-station service are:—High energy consumption, its inability to handle coal with high moisture contents, the dust nuisance incidental to disposing of the air in the coal at the delivery end, and cost of installation. One of its chief virtues is the ease with which a weighing system may be incorporated. By placing the tank on suitable scales, and making the connections to the tank of suitable flexibility, all coal transported may be readily weighed.

The continuous or Pump system (Fig. 8) consists essentially of a long steel or cast-iron screw or spiral driven at high speed in a cast-iron cylinder or barrel communicating at one end with a source of

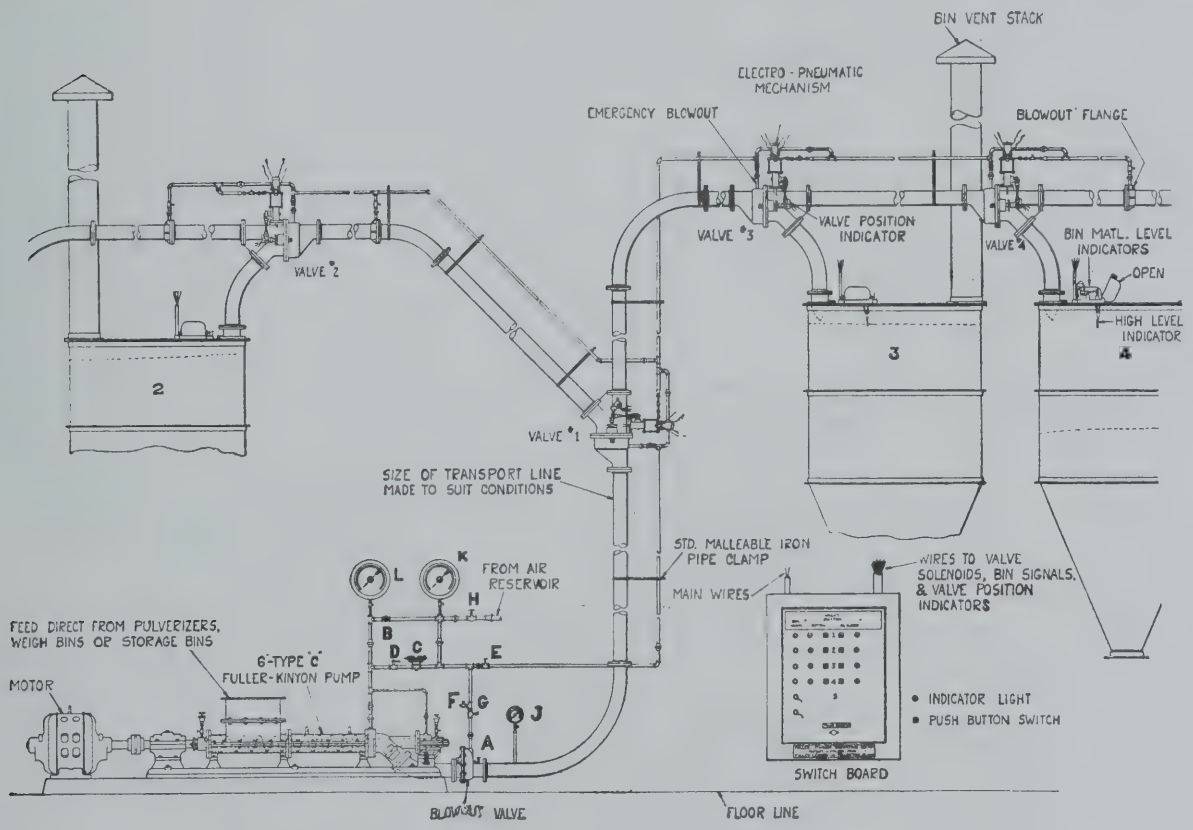


FIG. 8.—*Schematic Arrangement of Fuller-Kinyon System for Conveying Pulverised Coal.*

pulverised fuel and discharging at the other end into a pipe-line connecting with a distant bin at the point of consumption. The screw or spiral acts as a feeder and at the same time as a seal to prevent the backward flow of compressed air injected into the coal at the point where it leaves the screw and enters the pipe-line. Coal may be delivered by this system to any reasonable distance and height. Distances up to 2,000 ft., and heights of over 100 ft., have been dealt with successfully. The chief advantage of this system is that it permits the preparation plant to be located more or less independently of the layout of the boiler plant. The disadvantages are: High first cost, low moisture-handling capacity, high energy consumption, and dust nuisance from the bin vents arising from the discharge of the air used for transport. At the moment, there are many of these systems in operation, but with the increasing tendency to arrange the mills in close association with the boiler units, it seems probable that its use will decrease rather than increase.

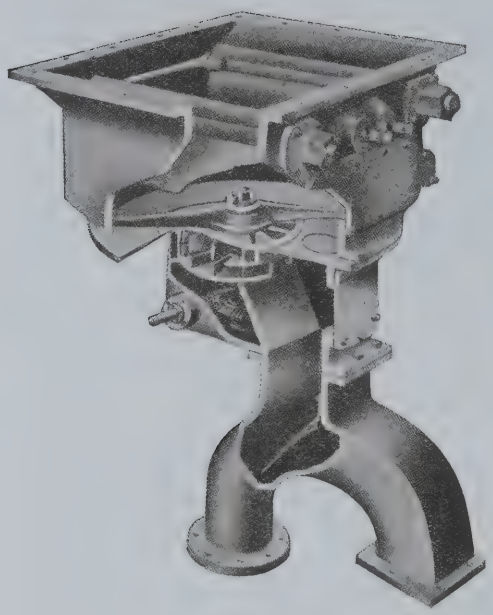


FIG. 9.—*Bailey Pulverised Coal Feeder.*

Properly designed and constructed, the screw conveyor is the most satisfactory form of transport. The trough should be of cast iron with machined joints and with a cover so designed that it may be easily put in place or removed, so that when it is put in place it forms a dust-tight joint with the top of the trough. The screw should preferably be of cast iron with the flights given sufficient rake to prevent packing of the coal and the ultimate jamming of the screw. For handling wet coal, the trough and preferably the cover also, should be lagged to prevent cooling of the warm coal and consequent condensation of moisture in the contained air. Conveyors of this class are normally installed horizontally, though they will function satisfactorily for delivering coal up a moderate incline. The chief advantages are :—Low first cost, very low energy consumption, high moisture-handling capacity, freedom from dust nuisance, low maintenance, and high degree of reliability. The only disadvantages are : Its lack of adaptability to awkward layouts and its limited usefulness as an elevator. With proper layouts, however, the disadvantages do not enter in.

Pulverised fuel bins.

By virtue of its position between the pulverising or preparation plant and the boiler, the pulverised fuel bin with its several hours' supply of refined product, is a most important safeguard against shut-down. With a supply of fuel available which has been delivered to the bin via an air current, to the cyclone separators of the pulverising system and from thence by the transport system to the bin, we may feel secure against the possibility of a shut-down due to the presence of foreign material in the form of rock, wood, large lumps of coal and bits of iron which may exist in the raw coal. The preparation plant must deal with the fuel in crude form, foreign material and all. The equipment is built to stand severe service, but is subject to interruption in operation due to breakdown, stoppage of feed due to arching of the fuel in the bunker, the coal spout and the feed hopper, to jamming of the feeder with foreign material, and to other unforeseen causes. Nothing short of a major breakdown requiring many hours for repair, however, causes an interruption to boiler operation,

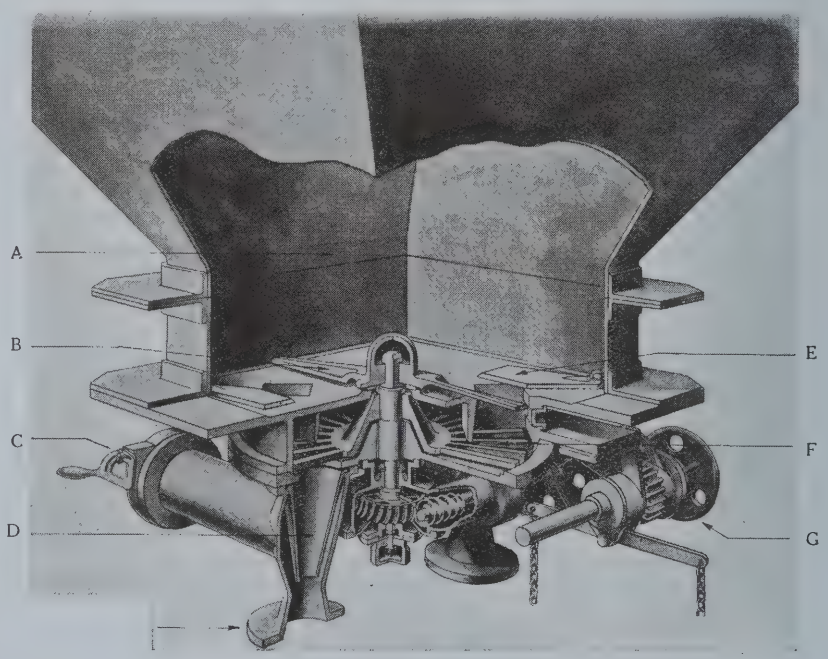


FIG. 10.—*Sectional View of Duplex Feeder Unit.* [*Patented*]
A.—P.F. Coal Bunker. B.—Agitator. C.—Air Inlet Damper. D.—Venturi.
E.—Coal Gate. F.—Star Feeder. G.—Driving Shaft.

and even then it does not occur except in the plant depending upon only a single unit of preparation plant. With more than one unit, the universal practice is to interconnect the various units through the pulverised fuel transport in such a manner that all of the preparation units become available to any or all of the boiler units.

The capacity of the pulverised fuel bin is a matter of judgment and compromise ; cost, space limitations, character of coal, and operating routine all play a part, A capacity of from eight to sixteen hours' operation at normal rating usually meets all requirements.

Bunkers may be constructed of concrete, or of steel plates with sides making an angle with the horizontal of not less than 60 degrees. One vertical side is an advantage but is not essential if the feeding mechanism incorporates a proper agitating device in the bottom of the bunker.

Bunkers should be thoroughly insulated, including the roof, to prevent trouble from condensation arising from cooling the air and the warm air-saturated coal. If constructed of steel, the insulation should preferably take the form of a lining placed inside, in order to secure the advantage of protection to the plates against corrosion.

Feeders.

Having been provided with a bin full of pulverised coal it would seem a simple matter to feed the coal to the furnace via the burners, and fortunately now that the problem is solved, we are able to state that this is the fact. The development of a thoroughly successful feeding unit, however, has not been free from disappointments along the way. In addition to the usual requirements of accessibility, reliability, etc., a feeder, to be fully successful, should prevent coal from arching in the bunker; should be but little affected in capacity or power consumption by moisture; should feed the coal uniformly without pulsation, and must be free from dust leakage into the room.

The screw feeder has definitely outlived its usefulness. Its faults are too well known and fully acknowledged to merit discussion. It has been superseded, however, by feeders which fulfil in a very practical way the qualifications of a successful feeder as enumerated above. Figs. 9 and 10 are examples of a type which has proved highly successful. As will be observed, both are characterised by a vertical shaft which rotates the feeder wheel and an agitator. The agitator prevents any tendency of the coal to arch, keeping the entire volume of coal in motion and ensuring a steady fluid flow of coal to the feeder wheel.

A special feature of Fig. 9 is the so-called fluffer wheel superimposed above the feeder wheel, but separated from it by a steel plate diaphragm. By virtue of the greater axial depth of the fluffer wheel its capacity is greater than that of the feeder wheel which it feeds through an open sector in the diaphragm plate between them placed at a point diametrically opposite to that through which the fluffer wheel receives its supply through the bottom of the coal bin. The feeder wheel, under the action of gravity, finally delivers its load into the current of primary air on its way to the furnace via the burner.

Fig. 10 differs from Fig. 9 in that one relatively large feeder wheel receiving coal from two diametrically located spouts through the bunker bottom, delivers its coal to two corresponding outlets displaced from the spouts by an angle of approximately 45 deg. The action of gravity in this instance is assisted by a blast of air through the wheel pockets when discharging. The air supplied from the primary air duct to the chamber above the feeder wheel flows under the influence of the differential pressure existing between the primary air duct and the throat of the venturi discharge pipe. As arranged, Fig. 10 is a duplex unit supplying two independent delivery pipes. Shut-off gates are provided, however, permitting the operation of either unit independently of the other.

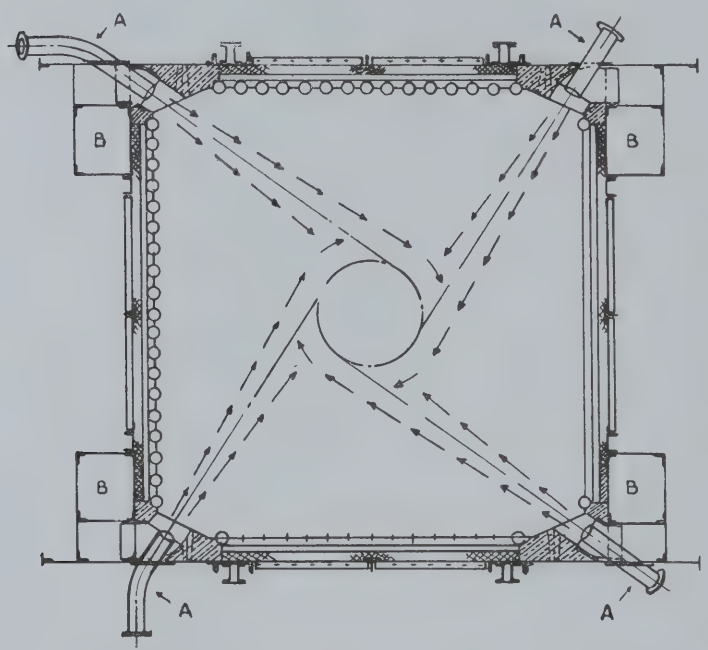
Combustion process.

The rapidity with which the process of combustion of pulverised coal may be carried out depends upon several factors. The following conditions may be stated as representing the ideal :—

1. The coal should be reduced to infinite fineness.
2. The coal and air should be preheated to the ignition temperature of the coal.

3. The coal and air should be brought together in correct proportions and as a perfect mixture at the furnace entrance. That is to say, each atom of coal should enter the furnace intimately associated with two atoms of oxygen to completely burn it.

Under these conditions, combustion would be instantaneous: the heat liberated per cu. ft. of furnace volume would be limited only by the rate at which combustible mixture could be delivered to it, and the furnace volume would be a function of the velocity of the mixture to it and of the combustion products from it. The time element for combustion to take place would not exist.



A. Primary Air and Coal Inlet Pipes. B. Secondary Air Inlet Boxes.

FIG. 12.—*Diagrammatic Sketch of Tangential Firing for Securing Furnace Turbulence.*

Practically, the ideal conditions can in no case be realised, since:—

1. It is neither practical nor economical to reduce coal to infinite fineness. The cost of pulverising equipment, its maintenance, and the cost of energy, are all factors which, taken together, establish an economic limit of commercial fineness.
2. The ignition temperature of coal varies with its composition, but in no case is it much below 900 deg. F. Theoretically, there is no reason why it could not be heated to this figure, but practically, it would lead to difficulties in handling, since in most cases the coal would become a sticky mass from which gas would be liberated in large quantities before reaching that temperature. In any event, there is little to be gained in this direction. The air conceivably might be preheated to the ignition temperature, but insulation, expansion, oxydisation, and costs of air preheater parts and ductwork, are all factors which establish a lower practical limit. Considering the imperfection of other factors influencing the combustion process, it is probable that little is to be gained by preheating the air beyond the more practical limit of 400 to 600 deg. F.
3. In the absence of infinite or atomic fineness, it is impossible to realise the intimacy of association of coal and oxygen specified as representing the ideal. If we modify our ideal to the extent of saying that each small unit of volume, say one cubic inch, should contain air and fuel in correct proportions for combustion, realisation should be approachable.

Even though unable to realise the ideals above enumerated, they are worthy of consideration and indicate the lines along which improvement may be sought.

To burn a coal particle of finite size requires time, even with all the other factors ideal. The larger the particle the greater the time required to obtain complete combustion. It follows from this that the time limit to obtain complete combustion of a coal-air mixture, under otherwise ideal conditions, is fixed by the size of the largest particle of coal in the mixture.

It will be evident from the above that, though coal fineness is usually stated as the amount which will pass through sieves having 100 and 200 meshes per linear inch, it is equally important that the percentage of coal retained on the coarser mesh screens be reduced to a minimum. It is the coarse coal particles which enter the boiler tube nest before combustion is complete and which, through becoming chilled and extinguished, are deposited in the rear passes of the boiler or pass out with the products of

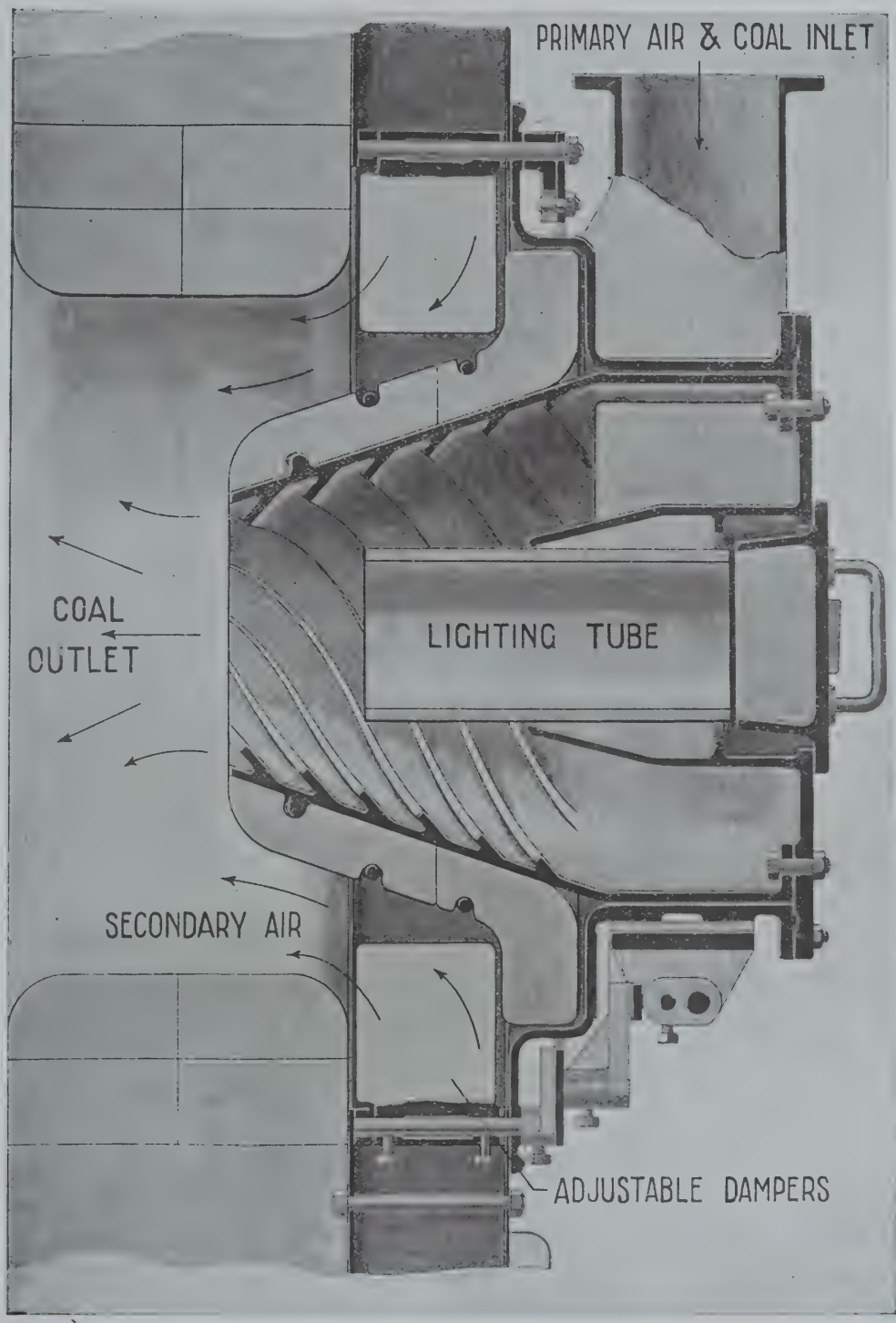


FIG. 11.—*Sectional View of Mixing Type Burner.* [*Patented*]

combustion as particles of coke. These constitute a definite and, in some instances, an appreciable loss in efficiency. Under favourable conditions as regards other factors, the loss may be less than 0.5 per cent. With unfavourable conditions, the loss may be as high as 4.0 per cent.

In the absence of the ideal of infinite fineness, the burner or fuel-air mixing device cannot attain the ideal set for it. The best it can do is to associate each particle of coal with its quota of air, or oxygen, for combustion. At 500 deg. F. temperature, the volume of air required to burn a particle of coal completely is roughly 20,000 times that of the coal particle, and at a furnace temperature of 2,500 deg. F. the volume becomes 60,000 times as great. It is not surprising, therefore, that the time required for a particle of coal to search out its quota of oxygen in a wilderness of nitrogen and products of combustion, forms an important element in the total time required for combustion. The smaller the particle, the less will be the number of oxygen atoms which it must seek out, and if the burner or mixing device has done its duty in closely associating the required number of oxygen atoms with each particle of coal at entrance into the furnace, the search will be facilitated and the time reduced to a minimum.

The sudden and violent expansion of gases caused by combustion, creates a high degree of furnace turbulence which, with a perfect mixture of fuel and air at the burner mouth, leaves little to be desired as an assistant to the coal particles in their search for their allotted oxygen atoms. With an imperfect mixture, however, such as all too often occurs, a burner and furnace arrangement which through impingement of conflicting currents of air and products of combustion augments the condition of furnace turbulence, will assist and accelerate the bringing together of the coal particles and their oxygen allotment and thereby bring about more rapid combustion.

It is frequently observed that rapid combustion is accompanied by high temperatures, and the conclusion is sometimes drawn that the rapid combustion is caused by high temperature—hence the advocacy of extremely high-temperature preheated air. Rapid combustion, however, is the result of good mixture derived either from a good burner or through furnace turbulence, or both, and high furnace temperature results from rapid combustion.

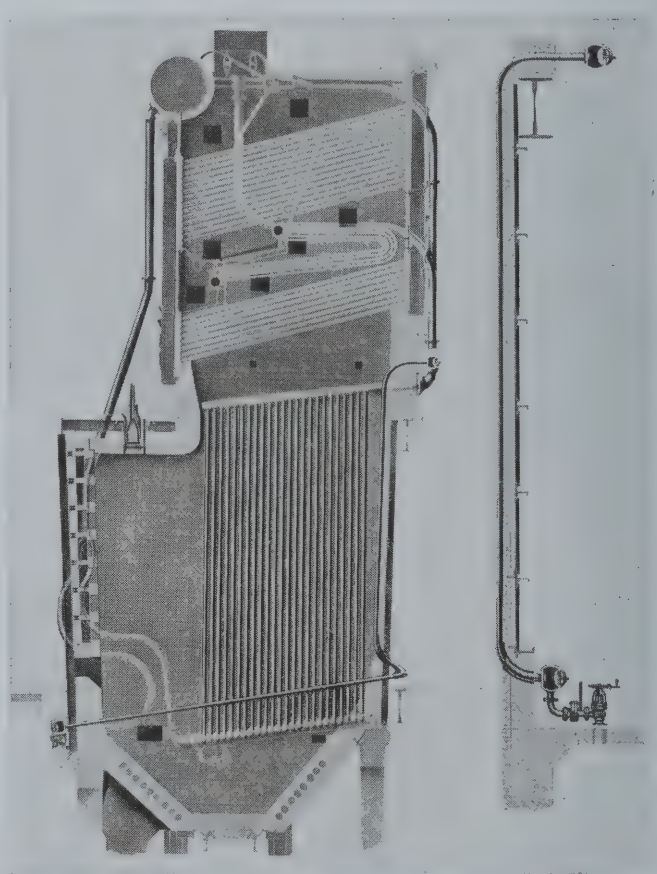


FIG. 13.—*Murray Fin Tube Furnace, Cahokia Station, St. Louis, U.S.A.*

Practical perfection in the combustion of pulverised fuel is attained when finely ground coal with a minimum of coarse particles is brought at a uniform rate, perfectly mixed at furnace entrance with the correct amount of air at the highest practical temperature, into a furnace so arranged with respect to the burners that all portions of the fuel mixture remain in the furnace an equal length of time. With such conditions, the furnace volume for complete combustion at a given rate will be a minimum, or conversely, with a given furnace volume and a given rate of combustion the loss due to incomplete combustion will be a minimum.

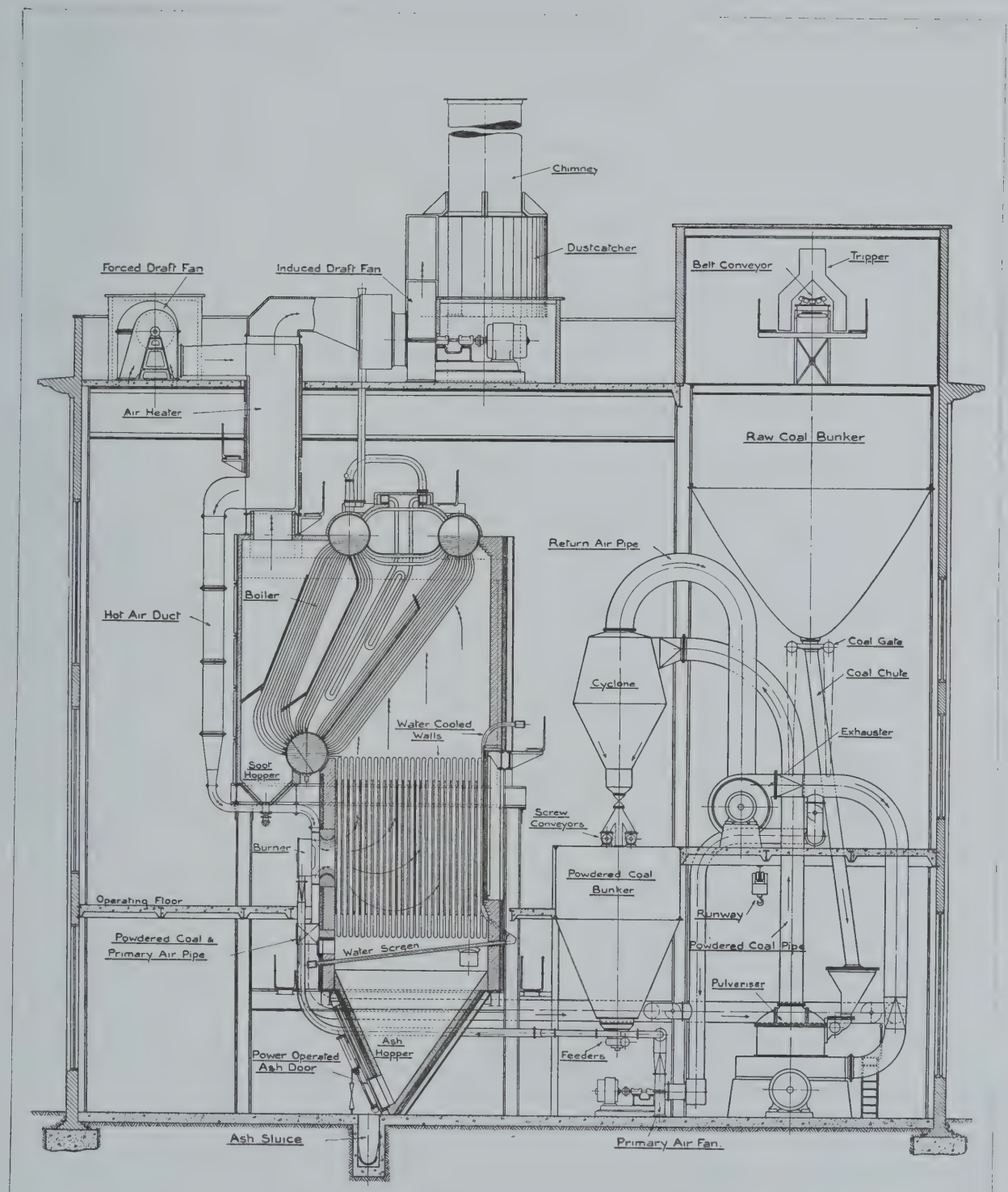


FIG. 14.—*Diagrammatic Arrangement Typical of Modern Plant.*

Burners.

The function of the ideal burner, when supplied with pulverised coal and air at a uniform rate and in correct proportion, is to deliver a uniform mixture of coal and air to the furnace. Up to a limit established by the design, it should perform this function, subject to easy adjustment, at all ratings. It should be uninfluenced by the external piping arrangement through which it receives its supply of coal and air. In the interest of low power consumption it should require low air pressure; it should be unaffected by the radiant heat from the furnace, and should be readily adaptable to furnaces of simple design and construction.

The function of the ideal burner, as described above, presupposes a furnace construction which will successfully withstand the effect of the high furnace temperatures realised. The early furnaces built completely of refractories would not stand such severe treatment, and the burners developed at that time claimed as one of their most important virtues their ability to distribute the heat in the furnace by delaying the admission of air and hence combustion at the expense of furnace volume. These types have persisted for new installations until quite recently.

Fig. 1 shows a typical arrangement of burning equipment of this class.

Improvements in furnace design and construction have reached the point, however, such that high localised temperatures are no longer a cause for apprehension, and hence, burners have been developed with the highest rates of combustion as their objective. Most of these contemplate a thorough mixture of the fuel with the whole of the combustion air at the point of entrance into the furnace, and some attempt, in addition, to secure a furnace turbulence. Fig. 11 is a typical example.

Another form of burner arrangement contemplates securing practically all the mixing of coal and air through furnace turbulence, by admitting air and coal through more or less independent ports at the four corners of the furnace. A coal and an air pipe at each corner is directed tangentially on to the periphery of an imaginary circle in the centre of the furnace. Fig. 12 illustrates the general idea.

Furnaces.

Much has been learned about practical furnace construction for pulverised coal in the past few years, and improvements are still going on. We have arrived at the point, however, where we may correctly say that the furnace is no longer the weak link in the chain.

The early installations for burning pulverised coal under steam boilers had solid refractory-walled furnaces which were merely an adaptation of stoker furnaces of the time. Serious difficulties were encountered, due to slagging of the ash and the rapid erosion of the firebrick walls. The furnace temperature was such that the ash fused and was present in the furnace atmosphere as a molten mist.

To minimise the destruction of refractory, furnaces were made extremely large in an effort to get the walls away from the flame. For the same reason, turbulence of the furnace gases was limited to the minimum at the sacrifice of rapidity of combustion, even in that portion of the furnace which was actively utilised. The water screen across the bottom of the furnace, by creating a cool zone, effectively overcame the slagging difficulty arising from the falling ash by causing it to solidify before it was deposited. This did not give relief, however, from the slag formation on the refractory walls. With increasing size of steam-generating units and the tendency to operate them at higher rates of evaporation per sq. ft. of surface, furnace dimensions rapidly reached embarrassing proportions. To obtain furnace walls of the required mechanical strength to prevent collapse and at the same time provide for expansion, became serious problems confronting the designer.

Hollow walls cooled by the air of combustion gave some relief, but erosion was still serious. Efforts to produce refractories at reasonable cost, which would resist the action of the molten ash, met with but small success. The chemical action between the molten ash and the refractory was a prime cause of the trouble, and the variation in ash composition as applying to various coals was so great as to render the solution most difficult. The failure to reach a satisfactory solution along this line diverted the minds of engineers into other directions.

Early in 1924 the original installation of the now well-known Murray fin-wall furnace construction, as applied to three retort-type stoker-fired boiler furnaces at the Hell Gate Station of the United Electric

Light & Power Company, New York City, went into commercial operation. The satisfactory results obtained in this installation drew the attention of a large body of engineers, but opinion was by no means unanimous as to the virtue of this construction for pulverised fuel furnaces, many feeling that the cooling effect of the walls would result in poor combustion.

At about the same time, the Cecil plant of the Allegheny Steam Heating Company went into operation with a large boiler fired with pulverised coal, The side and rear walls were protected with vertical 4-in. tubes, placed in front of the brickwork and connected into headers at top and bottom, the whole being connected into the boiler circulation. Several small boilers at the Sherman Creek plant of the United Electric Light and Power Company were also equipped with Murray fin-tube furnaces for pulverised fuel. The cooling effect of these tubes proved to have no injurious effect on combustion, and resulted in an order for a Murray fin-tube furnace being placed for one of eight large boilers in operation with pulverised fuel at the Cahokia Station of the Union Electric Light & Power Company, St. Louis (Fig. 13), where serious trouble was being experienced from brickwork erosion and slagging. This furnace went into operation in 1925 and its success was followed by a wide adoption of this form of construction in the United States, France, Germany, England and many other countries.

In the meantime, many other forms of water cooling for furnace walls have been developed, among which may be mentioned the Foster wall, and the Bailey wall.

Steam cooling of furnace walls should also be mentioned, in view of the considerable number of installations of radiant heat superheaters. As usually applied, they occupy a section of the furnace wall and are formed of a system of hollow forged-steel elements connected in parallel into headers at each end, through which the steam from the boiler drum is passed. The elements placed side by side form a continuous wall and are exposed to the furnace temperature.

Fundamentally, the application of steam and water cooling has become so well established that, except for very limited sections of wall, refractory construction for pulverised fuel furnaces may be considered obsolete. An exception should be made to this statement for the case in which a fuel having a very low volatile content, such as anthracite or coke, is to be burned. In such a case, the reverberatory effect of incandescent walls is at least desirable, if not essential, to maintain proper combustion.

The modern plant.

If we define a modern plant as being one built in accordance with up-to-date thought, we are forced to the admission that there are no modern bin and feeder systems of pulverised fuel plants in operation, nor is such a plant possible with the present rapid progress as applied to such plants. It occupies the best part of eighteen months to two years to express present ideas in iron, steel and other material, such as are required to construct a boiler plant. Plants are contracted for in accordance with a set of clearly defined, fixed ideas for completion in a given time, and to fulfil the obligation it is essential that the plan be rigidly adhered to. Two years, however, is a long time in a new industry—sufficient for the origination of many ideas, as affecting both detail refinements and fundamental features of equipment and plant arrangement. It follows, therefore, that the plant in process of design and construction is obsolete in many of its features upon completion, and that, so long as there is substantial progress in thought as applying to such plants, the only really modern plants are those in the proposition stage on the draughting board.

Fig. 14 is an example of a modern pulverised fuel plant. A study of the design and arrangement, in conjunction with the text of this chapter, will reveal that it incorporates most of the features recommended. Some sacrifices have been made, however, in the arrangement, in order to show the relationship of equipment more clearly. It will be observed that the assembly is fundamentally on a unit basis, *i.e.*, beginning with the raw coal bunker there is one pulveriser, one pulverised fuel bin and one battery of feeders and burners, serving one boiler unit. Drying is carried out in the pulveriser itself, with hot air from the air preheater; the milling system, at all points, is at a pressure below that of the atmosphere, ensuring no outward leakage of coal-laden air; all air withdrawn from the milling system is utilised as primary air and passed direct to the furnace, thus obviating any possible dust nuisance through the venting of dust-laden air to the atmosphere. Through the inter-connection provided by the screw conveyors, the excess capacity of any pulveriser,

over and above the requirements of the boiler unit which it supplies, may be transferred to the bin of a neighbouring boiler. Thus, there stands between the breakdown of any pulveriser and a shut-down of the boiler unit which it serves the coal in the bin at the time of breakdown, plus any excess capacity of neighbouring pulverisers serving other boilers. Through a bye-pass properly equipped with dampers, preheated air may be supplied to the primary air fan without passing through the pulverising system; thus, it is possible to operate the boiler with the pulveriser unit out of operation without inconvenience or sacrifice and the pulveriser operated at full capacity for only such period of the day as is necessary to supply the twenty-four-hour requirements of the boiler.

THE DIRECT-FIRED SYSTEM.

The appeal of the direct-fired system of pulverised fuel is based, primarily, upon simplicity and low first cost, and for small boiler units the pulverised fuel field is conceded to it without argument. In addition, space limitations will often dictate a decision in its favour, as it is more compact and hence more easily adapted to close quarters.

The system consists essentially of a pulveriser placed in front of the boiler under the raw coal bunker, substantially as used for stoker practice, a burner and furnace. No dryers, pulverised fuel transport, pulverised fuel bins, pulverised fuel feeders, etc., with which to contend. In view of the bad light in which this comparison places the bin and feeder system, the enquiring mind raises the question "By what virtue has the bin and feeder system made so much progress in competition?" That there must be important considerations in its favour to off-set its disadvantages, or that there must be some important disadvantages associated with the direct-fired system, is indicated by a consideration of the fact that the direct-fired system was for a long time in existence prior to the bin and feeder system.

It seems almost unnecessary to state that the furnace for the direct-fired system should receive the same careful consideration as for the bin and feeder system. Economy in construction can be made at the same sacrifice in durability and reliability with either system. The heat of a pulverised fuel flame is no respector of systems and attacks the furnace lining with the same vigour, regardless of what system is responsible for its production. It is a fact, however, that inferior furnaces are more often found associated with the direct-fired, rather than with the bin and feeder system; due, probably, to the fact that so large a proportion of the direct-fired installations are associated with small boilers furnishing steam to industrial plants, for a limited number of hours per day, and hence do not justify the expense of the most reliable modern construction. The mistake, however, should not be made of considering the saving in cost, a virtue of the direct-fired system.

The pulveriser is the all-important element in the direct-fired system, in fact, is the only element interposed between the raw coal bunker and the burner. It incorporates the feeder and deals with the raw coal direct, with all its variable conditions of size, moisture and ash content, in addition to such foreign material as may find its way into the coal. On it, therefore, rests the entire responsibility for the moment-to-moment operation of the boiler unit.

The type of pulveriser used for direct firing is almost invariably the high-speed beater type, of which Fig. 15 is typical, in that the coal is pulverised by the impact of the particles, first against the rapidly moving beater elements, and next against the interior of the pulveriser housing. No crushing action between metallic surfaces takes place. The pulverisers are invariably swept by an air current entering usually at the coal feed end and issuing through the fan at the discharge, carrying the finished product in suspension. From the fan the coal-air mixture flows direct to the burner.

A large number of pulverisers varying greatly in detail but answering to the above description is available. All, including the poorest and the best, have certain fundamental characteristics in common, from which the disadvantages of the direct-fired system arise. The following is an enumeration of some of the more important :—

1. Power consumption is equal to that required to drive the unit at no load plus a variable factor increasing with output.
2. The capacity is affected by the character of the fuel and its moisture content.

3. The pulverised product varies in fineness with output—the greater the output the coarser the product.

4. All have a maximum output, beyond which, if the rate of feed is increased, the unit chokes and ceases to function.

5. All are subject to wear, which, as it continues, results in a decrease in maximum capacity and in a coarser product at any given output.

6. All have the characteristic, inherent in high-speed machines subjected to severe service, of being subject to breakdown without notice.

In choosing a pulverising unit where one unit per boiler is contemplated, its capacity should be such that with the worst anticipated conditions of coal supply and moisture content, its output with the pulverising elements worn to a point requiring replacement, should be equivalent to the maximum contemplated output of the boiler unit. For flexibility and maximum boiler load its capacity should be somewhat in excess of this, particularly if the capacity of the pulveriser when operating with the particular coal under consideration is not known with accuracy, as is so frequently the case. Such a pulveriser, operating under favourable conditions with unworn beater elements, has a large excess capacity, the secret of satisfactory operation, though obtained at a high first cost and a sacrifice of energy for pulverising.

The hazard of interruption to service, incidental to an unforeseen breakdown, momentary failure of feed from any cause, such as arching or sticking of the coal in the bunker, coal spout or feed hopper, or by jamming of the feeder with foreign material such as iron, wood, etc., may be largely overcome by the installation of a multiplicity of units, which, for the maximum of reliability, should include one spare unit to be operated only under adverse conditions of coal supply or in case of breakdown of any unit. Such provision, however, contemplates under normal conditions an idle pulveriser and burner unit. As usually designed, an idle burner requires a liberal flow of air through it to protect it from the radiant heat of the furnace, a requirement accompanied by some loss in efficiency.

Combustion in the pulverised fuel furnace is essentially an instantaneous process, so nearly so that for any momentary variation in the ratio of fuel to air entering the furnace there can be no compensation. Uniformity of air supply through the unit is easily obtained. Corresponding uniformity of coal feeding, however, is most difficult, in fact, well-nigh impossible, owing to variation in size and the effect of moisture content. To the extent that a variation in coal feeding takes place a loss in efficiency results.

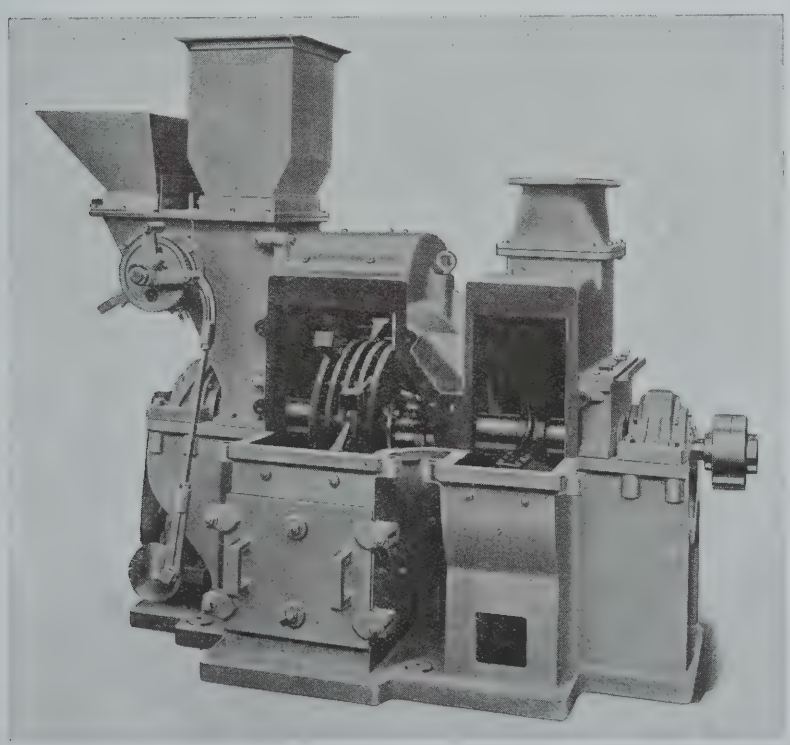


FIG. 15.—*High-speed Impax Mill for Direct Firing.*

The loss due to unburned carbon in the flue dust increases with the rate of combustion in the furnace, a condition which is aggravated, in the direct-fired system, by the fact that the pulverisers are operating at their maximum output under such conditions and hence supply coal of the maximum coarseness. The result is further aggravated as the pulverising elements become worn.

The maximum power consumption for operating the pulverising equipment must necessarily coincide with the peak load on the station; a matter of importance in stations nearing their capacity limit at peak load.

It was with the object of overcoming the above disadvantages that the idea of interposing a storage bin with feeders between the pulverising units and the furnace was conceived. It was argued that, by its introduction, continuity of boiler operation would be made independent of minor pulveriser breakdowns or momentary failure or variation in raw coal feed; the pulverisers could be operated at full output and need be of only such capacity that when so operated they would produce the 24-hour requirements of the boiler in a period of, perhaps, sixteen hours or less. The pulverising problems arising from variation in coal characteristics, moisture content, etc., could be dealt with without in any way affecting boiler operation; the pulverised product would be of uniform fineness for all rates of firing; spare pulverising equipment, in place of being required for each individual boiler unit, could be furnished to better advantage for the boiler plant as a whole; in case of the plant being loaded to capacity under peak load conditions, the pulverising equipment could be shut down and the peak load carried on stored fuel; a uniform flow of pulverised coal to the furnace could be more easily attained. The arguments were all sound, both then and now, a fact concerning which there is little dispute. Complications and cost of installation, together with unforeseen operating disadvantages associated with plants built and operating, however, are such as to have given rise to argument as to whether the advantages gained justify the disadvantages. A number of engineers whose experience and judgment demand that their opinions be treated with respect, subscribe to the negative view and are acting accordingly. Up to the moment, there is but little accumulated experience with the direct-fired system applied on a large scale; the operation of such plants now under construction, therefore, will be followed with great interest.

The lower moisture handling limit of the bin and feeder system, with the consequent necessity for drying, has contributed largely to the high cost and complications connected with this system. The space required for drying equipment led to the necessity, or at least the desirability, of a separate pulverising or preparation plant, which in turn required transport equipment for delivering the pulverised product to the boiler plant. Dust nuisances originating in the pulveriser vents, the discharge from dryers, and the vents from pulverised fuel bins receiving coal by air transport, were not foreseen. All, however, are contributing factors to the reaction at present taking place, to a limited extent, in favour of the direct-fired system. The writer, however, submits that the virtues of the bin and feeder system are such as are not to be lightly discarded, and justify a serious effort to overcome the disadvantages of the system. He is further convinced that, without in any way going outside the field of accumulated experience, it is now possible to construct plants retaining these advantages and which, at the same time, will rival the direct-fired system for simplicity of installation and first cost. Such plants, in fact, are now under design.

ASH EMISSION FROM CHIMNEYS.

The problem of ash discharge from the chimneys is one demanding consideration, particularly in the case of plants utilising high ash content coals and located in congested areas. The problem, however, is not peculiar to pulverised fuel firing. The volume of dust discharged is undoubtedly greater with pulverised fuel than with stoker firing, but its character is less objectionable. In either case, the situation is such as to justify means of overcoming the resulting nuisance. Perhaps one of the most effective means of avoiding complaint is that of resorting to high chimneys which, though they do not diminish the amount of ash discharged, result in its distribution over a wide territory, and have the further advantage of subjecting nearby neighbours to a lesser concentration of combustion gases. The real answer to the problem, however, lies in separating the dust from the gases before their delivery into the atmosphere. Development of suitable equipment is proceeding at a rate which promises an ultimate complete solution along this line. The efficiency of equipment now available in several forms is such as to very largely overcome the difficulty, though they still leave something to be desired.

ASH HANDLING

For pulverised fuel firing some form of wet handling is the most favoured scheme, though steam suction conveyors, industrial and railway car systems and screw conveyor systems are in use. Two wet systems are in use, namely, the sluicing system, which is by far the most popular, and the submerged drag-link system. For all the systems the furnaces are designed to deliver ash in the form of dry dust and small clinker.

The design of the furnaces at the Chas. W. Huntley Station of the Buffalo General Electric Company, and at the Calumet Station of the Commonwealth Edison Company, contemplate and secure a discharge of ash in molten form. This is reputed to be quite satisfactory, up to the point of leaving the furnace. From this point on, however, the scheme of handling requires further development, which, if ultimately satisfactory, may make this form of ash removal popular.

NATIONAL ELECTRIC POWER PRODUCTION.

By Sir Philip Dawson, M.P., M.Inst.C.E., M.I.Mech.E., M.I.E.E.

At first sight, it may not be apparent what relation the production of electricity bears to the important questions connected with the study of Britain's Fuel Problems. Fuel is the chief source of power in Great Britain, and with the ever increasing competition for the markets of the world, and the rise in the cost of production, due to shorter hours and higher rates of wages obtaining in this country, as compared with those of most of our foreign competitors, our industry will find it necessary, if it is to maintain its existence, to introduce the most modern methods which experience in other countries has shown to be closely bound up with electrification. Germany has realised this very fully, and last year 70 per cent. of all the motive power utilised by her industry was electric. The corresponding figures for the United States and Belgium were 65 per cent. and 56 per cent., whilst in Great Britain the figure was below 40 per cent. According to figures published by the Centralverband der Deutschen Electrotechnischen Industrie, in 1925, the total amount of electricity used, for all purposes, was 22,000 million B.O.T. units in Germany and only 11,000 million B.O.T. units in Great Britain.

Mr. R. Nelson stated, in a paper he read in April of 1926 before the Institution of Electrical Engineers, that "twice the amount of electrical power now employed could be utilised by our own coal mines with advantage." Prof. Hay, also, remarked in a paper he recently read before the Institution of Civil Engineers, "the conditions of our coal mining industry cannot be substantially ameliorated, except by a comprehensive linking up of the methods of power production and fuel utilisations."

In 1924, out of 2,855 mines only 1629 were partly or entirely electrified. In 1924 we had 65,000 pit ponies at work in our mines, and that figure has not been very materially reduced since. On the other hand, in the Ruhr area, where 8,000 pit ponies were previously at work, to-day there is scarcely one left, all the haulage being done mechanically.

In German coal mines, 6.5 watts of electric consuming plant is installed, per ton of coal gained, whereas with us the figure is only 2.6 watts.

Compared with the mines of the Pas de Calais in France, our mines are electrified only to the extent of 43 per cent. In the Pas de Calais practically all the coal is hewn or cut mechanically, while in England only 14 per cent., and in Scotland 47 per cent., is cut by machinery.

An increase in the labour-saving machinery at the coal pit, means an increase in the use of electricity, even if compressed air is used, as this is produced by means of electrically-driven compressors. Only by mechanical means, such as the use of conveyors, mechanical haulage, coal-cutting machinery, pneumatic picks, etc., can the tonnage of coal broken at the face be increased. It is by the greater use of electricity in the coal mining and steel industries, and by a closer co-operation between the producers of the three commodities, coal, steel and electricity, that their interests, as well as those of industry in general, can best be served.

A very good example of what can be done in this direction, is shown by the results so far achieved by the "Rheinish Westfalische Elektricitats Werke," which supplies an area of 5,500 square miles in the Rheinland, the Ruhr and Westfalia, with electricity. In 1925 to 1926, this company owned 1,300 kilometres of 110,000-volt transmission lines, and was constructing a 220,000-volt line to link up its own area with the power supply generated by black coal in the Saar, and with the hydro-electric stations in Baden, Wurtemberg and Bavaria, these latter, being already inter-connected with the hydro-electric plants of the Saar Vorarlbery, in Austria, and of the St. Gothard and Simplon in Switzerland; so that eventually there will be an interchange of power between the black and brown coalfields of the Rhine and the Ruhr, with the water powers of Southern Germany, Austria and Switzerland, the distance from the Ruhr to the Alps being over 400 miles.

This company, which does not distribute, but only supplies very large consumers and authorised distributors, in addition to its extra high-tension overhead lines already referred to, owns 13,000 kilometres of 25,000-volt to 6,000-volt transmission lines, and in the year 1925-6, it sold 1,157,798,847 B.O.T. units to 300,000 consumers, and of this amount only 74,541,711 B.O.T. units were used for lighting, the remainder

being sold for power purposes. This company not only supplies electricity, but also collects the surplus gas from blast-furnace and coke-oven plants which is not used by the works themselves for heating or power purposes, and supplies it by means of a high-pressure main 240 kilometres in length, to a large number of adjoining gas undertakings. The amount of gas thus disposed of was 69,629,347 cubic metres in 1925-6, but before the Ruhr occupation by the French the quantity amounted to 81,400,000 cubic metres.

This is only one of several large German undertakings engaged in similar work, some of which exchange current, and all of which are, or will be, interlinked with each other in the near future. How far this process has already been carried out may be seen from the map presented.

Sweden is now linked up with Norway, and is supplying Denmark by means of a high-tension cable, laid under the Sound.

France is completing an extra high-tension overhead transmission system, which will link up the water powers of the Pyrenees and the "Massif Central," with the coalfields of the Pas de Calais. We see from this that, in the very near future, the hydro-electric power of Norway and Sweden, with supply and inter-change current with Germany, will, in its turn, be linked up with the water powers in Austria and the Swiss Alps, the water powers of the French Alps, the Pyrenees, the "Massif Central," and the black coalfields of Polish Upper Silesia, the black coalfields of the Saar and those of the Pas de Calais. Austria

Map showing inter-linking of electric lines in Germany.

Map showing proposed control distributing stations in England.

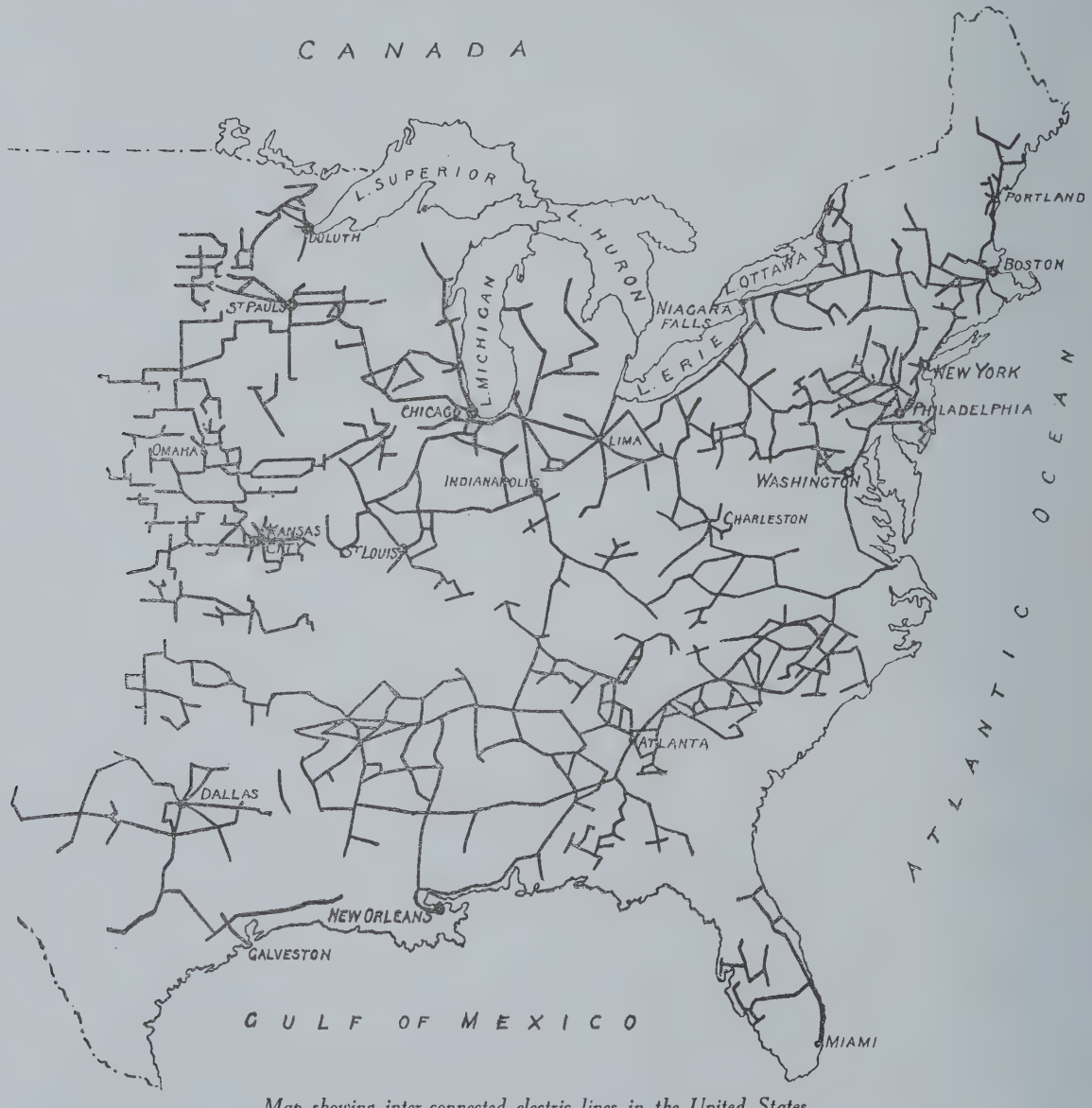
and Switzerland are already linked up with Italy and France, and will, undoubtedly, be linked up with Spain. So that it is within sight, that an extra high-tension network of overhead transmission lines will cover Europe, just as to-day Europe is covered by a network of railways, and that into this network all the power supply undertakings will pump energy to the benefit of the producer as well as of the consumer. The United States are progressing in the same direction, as is clearly shown by the map. The Electricity Act of 1926, will, it is hoped, secure similar results for Great Britain.

Hitherto, the districts favourably situated from the point of view of economic generation, with cheap fuel, plentiful water supply and an industrial and densely populated area, might expect to be able to obtain relatively cheap electricity, while less favoured districts either had to pay very high rates for electricity supply, or go without it altogether. But, even in the case where favourable conditions were encountered, the greatest economy in generation could not be attained, mainly as the result of the large proportion of spare plant which had to be provided, for the reason that large units are essential for efficient and cheap production of current, and that the spare plant required is not a percentage of the total plant installed, but generally consists of at least two spare units, one to take the place of a machine being overhauled, and the other to be put into service in case of a breakdown.

Thus, in a station having a maximum load of 60,000 kilowatts only two machines of 30,000 kw. each would be needed for service purposes, and two spare machines would also be needed, or 100 per cent. spare.

We find that in 1925 the capacity of the plant installed in our electric public utilities was 62 per cent. in excess of the maximum demand of that year. Co-operation between all the supply authorities is

obviously the solution of the difficulty, because if a considerable number of large and efficient stations work together into one supply network, the spares in one station serve as spares for all others, and the result of experience in other countries has shown that, when inter-convention and co-operation is carried out on a large scale, the spare plant can be reduced certainly 10 per cent., and even below that figure. This point was realised as far back as 1909, and legislation was then passed enabling interlinking to be carried out and bulk supply to be provided to neighbouring districts, not favourably situated to produce cheap electricity.



Map showing inter-connected electric lines in the United States.

Owing to the lack of co-operation between adjoining authorities in 1925, only 7.6 per cent. of the total electricity supply was bulk supply.

With a view to furthering the more general use of electricity, the 1919 Act was passed, again depending for its success on voluntary co-operation, which, unfortunately, was not forthcoming.

In connection with the generation and supply of electricity, it must be borne in mind that, unlike gas or solid fuel, electricity cannot be economically stored in any quantity, so that the amount generated must, at all times, be equal to the actual demand and the production has to fluctuate with the demand.

Hence, the benefit of fitting in loads, whose hours of demand do not coincide, so as to reduce the difference between maximum and minimum loads, and to make the load as even and as continuous as possible. This result is also obtained by spreading the supply over large areas having diversity of load, these areas being fed by interlinked stations, the larger of which supply the basic or continuous portion of the load, whilst a few stations, possibly less efficient and where capital expenditure must be kept down as low as possible, are operated only to take the peak load.

It is obvious that, to secure the best results, all the stations feeding into the bulk supply network, must be operated in the common interest and controlled, both as regards the plant that should be installed and the method in which it should be operated, by a central authority, whose sole aim must be to secure efficient, economic, and reliable generation and transmission.

No station should, for the sake of the common good, be allowed to continue to operate, when current can be secured as cheaply from the main transmission network as it can be generated locally, taking all the factors such as interest, sinking fund, cost of operation, maintenance and administration of the transmission system into account.

Hitherto, as practically each distributing authority generally generated its own supply, it was impracticable for efficient stations to transmit long distances, or to supply outlying or distant distribution authorities.

In addition to the points already referred to, there are many cases where large works, such as collieries and steel works, generate for their own requirements, their conditions of load and cost of fuel often favouring such a course. By the grouping together of a considerable number of collieries, to generate for their own requirements, cheap current is rendered available, and it would cost relatively little to increase the size of such stations, which burn a very poor class of fuel, and which it would otherwise not pay to bring to the surface, as the cost of transport makes it unsaleable. These stations, hitherto, with few exceptions, had no outside customers, but with a high-tension network covering the country, it will be an easy matter to connect them up, thus, to enable them to pump all their surplus current into the network which will distribute the bulk of the current generated all over the country. The same thing applies to steel works and coke ovens where much gas which is even now exhausted into the atmosphere, could be used to produce electricity. Such a scheme is being operated on the North East Coast, but this only represents a fraction of what can be done in Great Britain, in this direction.

The progressive adoption of oil as a source of power for ships, and the growth of motor traffic, as well as the need for more efficient methods of production, must reduce the amount of coal which this country can dispose of in the ordinary way, both at home and abroad, notwithstanding any growth that may take place in trade and industry. Hence, the need for increasing the uses of coal, and of increasing the intrinsic value of the ton of coal, as well as utilising products such as very inferior coal of high ash content, cannel coal and torbanite, by extracting the oil, tar, paraffin and other by-products, and employing the residue as fuel.

In low-temperature carbonisation, large quantities of gas are produced for which, hitherto, it has been difficult to find a market. The use of gas to generate electricity, for which as a result of the 1926 Act there will always be a purchaser, will greatly assist the development now taking place in the extraction of by-products from coal, whereby the value of our fuel resources will be enhanced.

Electricity is still, in many cases, looked upon principally as a source of light, and the proportion of electricity used for lighting, as compared with that used for power purposes to-day, is far too large in Great Britain.

Experience in the United States and on the continent of Europe has shown that inter-connection has greatly improved the continuity of supply, and very materially reduced the amount of spare plant required. In addition to this it has increased the efficiency of production, as a result of which, a corresponding decrease in the cost of production has occurred. How far more efficient production may affect the coal bill, is shown by the fact that whereas the average coal consumption in electric public utilities in Great Britain in 1926 was 2.55 lbs. per unit generated, the most efficient station to-day produces it for 1.56 lbs. of coal, and with the higher steam pressures and higher steam temperatures now being adopted on the Continent and the United States, we can look forward to a still further reduction, perhaps bringing the coal

consumption down to 1.22 lbs., per unit generated. The average thermal efficiency of the electric public utilities in 1903 was 5 per cent., in 1924-25 it was 16.3 per cent., but with our most modern stations, 30 per cent. thermal efficiency is well within sight, and with higher steam pressures and steam temperatures, pressure up to 100 atmospheres is now being operated, experimentally, on the Continent, 40 per cent. may be reached in the future. The Langerbrugge Station, in Flanders, is working with a steam pressure of 710 lbs. and 822° F. temperature, at the stop valve of the turbines. The turbine efficiency which, in 1912, was 70 per cent., has now been improved to well over 80 per cent.

Greater efficiency in the utilisation of fuel in our industry is essential, and in this direction electricity can be of the greatest service, provided our large industries, more particularly those of coal and iron, realise the need of co-ordination, co-operation and modernisation.

An application of electricity which, so far, has received little or no attention in this country is in connection with farming. The education of the farmer is necessary, so that he may be the better able to appreciate the service electricity can render. In no country has a greater development in this direction taken place than in South Sweden. The war was originally responsible for this development and the need of finding some substitute for coal. Experience has shown that in purely rural areas where there is little or no industry, the average consumption per head of population, exclusive of that used in the towns, is 34 B.O.T. units per head of population, and this corresponds with 400 B.O.T. units per annum, per consumer connected up. Electricity is used for all pumping purposes, chaff cutting, milking, working separators, straw presses, winnowing, oil-cake crushers, thrashing, supply of hot water, cooking, loading and unloading and transporting hay and straw, as well as for lighting. In order to enable such rural electrification to be carried out, the existing rules relating to the installation of overhead mains in Great Britain will have to be modified. Thus we find that, if the regulations obtaining in Sweden were applied to rural electrification, the transmission and distributing lines would cost about one third of what they would, if constructed under the existing British regulations.

The supply of electricity, naturally, divided itself into two parts, that of generation and transmission and that of distribution and selling to the individual customer.

The best results in generation and transmission can only be obtained by the closest co-operation between all the sources of production, both as regards the plant to be installed, and as regards its operation. This can only be brought about by unity of control. It is to effect this purpose that the Central Electricity Board has been set up, by the Act of 1926.

It will not own or operate, but will co-ordinate and control the principal sources of electricity supply, which will be owned and operated by private or municipal enterprise as hitherto. The supply of the whole country will, so to speak, be pooled for the benefit of the whole country, and all the sources of supply will pump into a transmission network or grid which will interlink them. Each distributor will obtain all the current he requires, and if his station is operated under the direction of the Central Electricity Board, he will purchase at a price which will in no case be greater than that which it would have cost him had there been no Board, but which may, and probably will, cost him materially less.

By this means, a grid similar to those which exist on the Continent of Europe and in the United States, will come into being in Great Britain in the next few years. The Board have the right to purchase any excess energy generated by waste heat installations, or by colliery companies or steel works, chemical works, or isolated water power, which will be pumped into the grid and which will enable waste heat stations to supply distant districts through the grid and thus find an output for the current they produce which hitherto was impossible.

All generating stations within reach of the grid will be shut down, wherever the cost at which current can be supplied to them from the grid, is no greater than the cost at which they can produce themselves.

In order to render the co-operation and co-ordination of the various sources of supply possible, the frequency of all stations co-operating must be standardised, and the cost, as far as interest and sinking fund on this is concerned, will become a working charge on the Board, until the amount involved has been wiped out.

It has been estimated that, when the complete proposals for the whole country have been carried out, the total expenditure of the Board, including interest, sinking fund, maintenance and operation of and losses in the transmission system, interest and sinking fund on the capital, required to carry out standardisation of the frequency and the general cost of administration, will be 0.035d. per B.O.T. unit sold by the Board, and that in the first scheme to be carried out in Scotland this will not exceed 0.046d. per unit.

The reduction in the amount of spare plant required, from over 60 per cent. to under 10 per cent., the larger output and better load factor which inter-linking will secure to the generating stations operating under the control of the Board, should much more than offset this amount.

Distribution is not practically interfered with under the 1926 Act, as it is a purely local matter, depending on the knowledge of individual conditions and requirements, and on progressive tariffs and propaganda.

It will thus be seen that by the 1926 Act a real national supply of electricity will be secured, though not a nationalised one, and that the subject of electric supply has been excluded from the political arena and cannot be interfered or tampered with by any political interest in the future.

Chapter 1.

FUEL CONSUMPTION IN THE BRITISH IRON AND STEEL INDUSTRY.

By Edgar C. Evans (National Federation of Iron and Steel Manufacturers).

Fuel represents the largest single constituent in the cost of iron and steel production. The consumption of coal in the production of iron and steel in Great Britain in commercial forms, coming within the purview of the National Federation of Iron and Steel Manufacturers, amounted in 1925, to 21,291,700 tons, of which 12,485,700 tons were used in the production of 6,261,700 tons of pig iron.

The coal consumed in the production of finished material varies with the class of product produced, forgings and small sections for example, necessitating the use of more coal than large sections.

Accurate comparison of British fuel practice in the iron and steel industry with that of competitive producers is, therefore, difficult, but on the whole:—

(1) British blast furnaces use more fuel proportionately than those in other countries.

(2) British steel making and rolling mill practice compares more favourably with the Continent than blast furnace practice, but average practice in this country is probably behind that of the Continent.

A number of factors are involved, two of which are fundamental, namely:—

(1) In Great Britain the industry has evolved under cheap fuel conditions.

(2) Great Britain was a pioneer in the industry, so that the Continent commenced with the advantages of British experience and technique.

Fuel costs in iron and steel producing countries.

No figures are available as to the present cost or even consumption of coal in the various countries, per ton of finished material, but some information is available regarding coke consumption in blast furnace practice. Official figures for some of the producing countries are given in Table I.

Table I.

	Production of pig iron in 1925, tons.	Ore and limestone cwts. per ton pig.	Coke, per ton pig, cwts.
United States	36,700,566	46.8	19.08
*Germany	10,176,699	—	21 to 22‡
*France	8,494,111	60.0‡	24 to 25‡
Great Britain	6,261,700	58.8	25.72†
*Belgium	2,541,430	56.0	21.2
*Luxemburg	2,363,253	66.0	23.3
Canada	596,475	47.5	19.8

* Output in metric tons. ‡ Estimated.
† Includes the coke equivalent of raw coal charged in some districts.

From these figures and others available the average coke consumption in Great Britain is higher than that of Continental countries smelting a somewhat similar proportion of material, per unit of pig iron produced. Sufficient information is, however, not available as yet to allow of a detailed comparison, but some assistance is given by Tables II. and III., which show that the highest coke consumption (disregarding alloys) is obtained in basic, foundry and forge furnaces, using a total charge exceeding 65 cwts. per ton of pig iron, frequently using inferior coke and often of small capacity.

From a study of such individual records as are available of figures of Continental furnaces, it appears probable that the higher coke consumption in Great Britain as compared with the Continent, is connected with:—

(1) The higher proportion of foundry and forge iron made in this country, necessitating higher coke;

(2) Smaller size and lower rate of driving of furnaces in this country, with consequent higher radiation and external cooling losses per unit of product.

In the case of finished iron and steel sections, comparisons of British and Continental practice are much more difficult, as conditions vary so much, but Continental practice is probably superior, due to a great extent to the fact that it had to meet dear fuel conditions practically from the outset.

Comparisons of fuel prices on the Continent with those of this country are not easy, as they differ so much for each district and at different works, but a general view of the position can be ascertained from a consideration of Table IV. which gives the ore and coke produced and consumed in 1925 in the four most important Continental producing countries.

During 1925 Great Britain produced 6,261,700 tons of pig iron, using 7,465,600 tons of coke. In the same year, the total quantity of metallurgical coke produced in this country from by-product and coke ovens, amounted to 11,008,686 tons, so that there was an ample margin between the requirements and the production. The only other country which produced coke in excess of its requirements was Germany. Figures for coke consumed in pig iron manufacture in Germany are not available, but assuming an average consumption of between 21 and 22 cwts. per ton of pig iron, there was evidently a large proportion of coke available for export purposes.

Information of coke consumption in pig iron manufacture in France is not available, but assuming an average of 24 to 25 cwts. of coke per ton of pig, there is a deficiency in that country of the order of between four and five million tons per annum.

Belgium, whilst it produces more coke than is used in the production of pig iron (largely from German coal) still has to import about 600,000 tons of coke per annum, whilst in Luxemburg, the whole of the coal and coke used in the industry has to be imported.

The position, therefore, of the iron and steel industry of the Continent is dominated by the cost of Westphalian coal and coke delivered at the works. Whilst in some producing districts there are other sources available, the market price would still, to a great extent, depend on that of German coke, the transport charges on which would be considerable. Except, therefore, in the Ruhr itself, fuel prices on the Continent would necessarily be generally higher than in this country. This position has existed practically from the inception of the industry. Thus Bell (Principles, page 612, et. seq.) gives the following prices in 1885 for coal and coke in Continental producing districts compared with a Durham price of 12/4 per ton for coke delivered at Middlesbrough.

Dortmund. Coal price, yielding 70% coke	7/-
Pas de Calais (coal price)	12/8—13/6
Belgian (coke price)	12/6—13/-
Moselle. Saar coke	15/-
Westphalian coke	17/6
Belgian coke	20/-
Luxemburg. Westphalian coke	17/7½
Belgian coke	17/1½
Nancy. Coke	20/-—21/8

Except in Belgium, fuel prices even at that date were considerably higher than in this country, so that the industry was built up in those areas under dear fuel conditions and these have persisted practically throughout the last 40 years.

During the period 1885 to 1913, British coal prices gradually increased from an index figure of about 55 in 1885 to one of 100 in 1913, in which year the actual cost of production of disposable coal in this country was about 9/6 per ton as compared with a figure of 11/9 in the Ruhr (evidence of Mining Association to Coal Commission, 1926).

TABLE II.—MATERIALS CONSUMED IN THE PRODUCTION OF PIG IRON, 1925.

NOTE.—Information as to materials consumed in the production of pig iron was received from firms producing 96 per cent. of the total production of the country; the materials consumed in the production of the remaining 4 per cent. have been estimated.

	Hematite.	Basic.	Foundry and forge.	Alloys.	Other qualities.	Combined qualities.*	Total.
	(Tons.)	(Tons.)	(Tons.)	(Tons.)	(Tons.)	(Tons.)	(Tons.)
Total production of pig iron	1,908,600	2,064,500	1,927,500	184,900	73 100	—	6,261,700†
Production of pig iron for which particulars are given	1,908,600	1,439,300	1,783,700	184,900	52,200	893,000	6,261,700
Materials consumed — Iron ore, Home	962,900	3,279,800	4,361,300	5,400	116,700	1,531,300	10,257,400
Materials consumed — „ „ Imported	2,422,900	574,000	539,700	376,300	12,300	628,400	4,553,600
Materials consumed — Limestone	817,500	291,300	870,700	122,100	22,200	352,500	2,476,300
Materials consumed — Other materials‡	160,200	540,900	222,200	6,600	13,200	176,100	1,119,200
Total charge	4,363,500	4,686,000	5,993,900	510,400	164,400	2,688,300	18,406,500
Fuel consumption — Raw coal	215,400	24,200	542,700	—	31,000	72,500	885,800
Fuel consumption — Coke	1,931,400	1,862,600	2,147,500	392,200	60,100	1,071,800	7,465,600
Total coal equivalent	3,240,900	2,933,800	3,875,000	606,800	121,900	1,707,300	12,485,700

* The figures under "Combined qualities" represent the production and materials consumed by firms producing more than one kind of pig iron who were unable to divide the materials consumed among the different processes. The production includes:—Basic, 625,200 tons; Foundry and Forge, 143,800 tons; Other Qualities, 20,900 tons; Direct Castings, 103,100 tons.

†Including 103,100 tons of Direct Castings.

‡Cinder and Scale, Purple Ore and Scrap.

TABLE III.—MATERIALS CONSUMED, PER TON OF PIG IRON PRODUCED, 1925.

Quality.	Materials consumed.							
	Iron ore.		Limestone.	Other materials.	Total charge.	Coal.	Coke.	Total coal equivalent.
	Home.	Imported.						
	(Cwts.)	(Cwts.)	(Cwts.)	(Cwts.)	(Cwts.)	(Cwts.)	(Cwts.)	(Cwts.)
Hematite	10.09	25.39	8.56	1.68	45.72	2.26	20.24	33.97
Basic	45.58	7.98	4.05	7.51	65.12	0.34	25.89	40.78
Foundry and forge....	48.92	6.05	9.76	2.49	67.22	6.09	24.09	43.46
Alloys	0.59	40.70	13.21	0.71	55.21	—	42.42	65.60
Total (all qualities) ...	32.75	14.54	7.91	3.58	58.78	2.83	23.84	39.89

TABLE IV.—ORE AND COKE IN CONTINENTAL IRON AND STEEL COUNTRIES, 1925.

(Metric tons.)

	Ore used for pig iron manufacture.	Ore imported.	Ore exported.	Home ore produced	Coke used for pig iron manufacture.	Coke made.	Coke imported.	Coke exported.
Germany	—	11,540,010	201,742	5,000,000*	—	26,810,094	69,000	3,776,000
France	23,198,877	871,069	9,226,688	35,741,195	—	4,287,000 (1923)	—	—
Belgium	7,329,560	—	—	—	3,013,900	4,108,300	652,510	848,458
Luxemburg	7,876,462	2,934,546	—	—	2,750,935	—	—	—

*Estimated.

Under these conditions, whilst on the Continent every possible effort had to be made to conserve fuel, and capital expenditure on fuel saving devices and plants was absolutely necessary, in this country it was frequently difficult to justify such expenditure, as capital charges frequently were such as to outweigh reduction in fuel costs that would be obtained. Similar conditions existed in the United States, another cheap fuel country. H. A. Brassert, for example, in a contribution to the International Conference on Bituminous Coal to the Carnegie Institute in 1926, writes as follows:—

> " It is generally acknowledged that, during the great development through which the American iron and steel industry has undergone since the discovery of the Mesabi Range, refinements pertaining to fuel economy, unless resulting in greater production as in the case of lower coke consumption per ton of iron at the blast furnaces, were generally considered last on the programme of improvements. Sound reasons governed this policy, principally scarcity of labour combined with unlimited markets. Greater output and labour saving were the chief purposes. American blast furnaces, steel works and rolling mills took the world's lead in production, mechanical devices for labour saving, more efficient scheduling of work and application of labour. The iron and steel industry in this country compared to that of Europe excels in the rational development of balanced output integrated from raw materials to finished products; in simple layout and construction of plant, free from elaborate complications; and also in cost accounting. It also has the advantage of better standardisation of production and products.
>
> " Capital as a general rule, was not so readily obtained for building economical gas, steam and power plants, or for the more efficient recovery of the values contained in surplus gases. Complete cleaning of blast-furnace gas was not considered economical except for gas engines, and primary washed, and, in some cases even dirty gas is to this day used under stoves and boilers. Coal firing of boilers and heating furnaces in American steel plants is in many instances still carried out without regard to efficient combustion. All this holds true in England. Waste heat boilers in connection with open hearths, it is true, have been developed in America ahead of any country, but their installation was induced in part by a condition resulting from the desire for greater tonnage, necessitating a greater heat input, generally resulting in higher stack temperatures, an effect which may only be modified by the application of the most recent refinements in design and operation."

In this country, whilst no doubt there has been a great improvement in the efficiency of plants during and since the war, these improvements were directed primarily to increase productive capacity and only incidentally to improve fuel efficiency. The rapid change-over, therefore, from cheap to dear fuel conditions which occurred during the early post-war period, found this country unprepared. The Board of Trade Index No. for wholesale coal prices averaged in 1920 332.1 as compared with 100 for 1913, the subsequent index numbers being as follow :—

TABLE V.—B.O.T. INDEX NOS. OF WHOLESALE COAL PRICES. 1913 Index No.=100.
Average for 1920, 332.1; 1921, 242.9; 1922, 171.7; 1923, 179.3; 1924, 172.3.

	1924.	1925.	1926.	1927.
January	179.7	158.5	142.0	*
February	183.5	156.2	141.6	*
March	189.4	152.9	139.3	147.1
April	192.3	150.6	142.1	138.8
May	180.5	148.9	*	130.5
June	170.3	143.9	*	123.1
July	167.6	145.6	*	119.8
August	163.7	141.9	*	
September	163.1	139.1	*	
October	160.4	138.2	*	
November	160.1	138.0	*	
December	164.0	140.7	*	

* Coal Strike.

It would be rash to attempt to prophesy the future development of coal prices, but there is no doubt that the experience gained during the past few years with dear fuel conditions has led the industry to devote special attention to this branch of technology, and as capital becomes available a greater development in fuel efficiency will be obtained.

Efficiency of British and Continental plants.

Low fuel consumption in the production of finished iron and steel sections necessitates, under ideal conditions:—

(1) Concentration of coke ovens, blast furnaces, steel works and rolling mills on a common site, so that the surplus gas from the coke ovens and blast furnaces can be used in the steel works and mills.

(2) Complete balance of the works as a whole, and a capacity large enough to allow of optimum efficiency.

(3) Operation of the works at the highest possible capacity.

Owing to the pioneering conditions under which the industry was developed in Great Britain, these ideals are only rarely attained. Iron and steel production had attained large dimensions in this country a generation before production on any scale commenced abroad. During the period from 1850 to 1885, British technologists had developed a technique which could only rarely be fully embodied in the older works frequently restricted as they were in extent and character of site, character of products made and raw materials available, layout of existing plant, and so on. Under the cheap fuel conditions existing in England, steel furnaces, for example, could frequently be operated successfully apart from blast furnaces, whilst even blast furnaces making forge or foundry iron, and in some cases steel-making iron, were not necessarily located near the steel works. Before rational utilisation of blast-furnace and coke-oven gas became developed to its present stage it was frequently more economical to erect coke-oven plants near the collieries than to carry the raw coal to the blast furnaces and steel plants. Even under conditions when coke-oven gas was available within a few miles of the steel works, the cost and difficulty of securing wayleaves, together with the congestion of the area in which the works were situated, prohibited any attempt to utilise coke-oven gas for steel production.

Whilst a few plants, then, in this country may be regarded more or less as self-contained, the majority have to depend upon the use of extraneous fuel other than that available from blast furnaces and coke ovens for heating and power production.

Difficulties with respect to balance of plant have been accentuated, due to the war developments. Thus the increase of capacity since 1913, of pig iron, ingot steel and finished sections is as follows:—

	Capacity in 1913.	Capacity in 1925.
	Tons.	Tons.
Blast furnaces	11,000,000	12,000,000
Steel works (ingots)	8,000,000 over	12,000,000 over
Rolling mills and forges (finished materials) ...	7,000,000 to	10,000,000 to
	8,000,000	11,000,000

Thus, whilst before the war blast furnaces had a capacity of approximately 3,000,000 tons per annum greater than that of steel works, the capacity to-day is approximately equal, and if the requirements of pig iron for foundry and forge purposes are considered there is a deficiency of pig iron for steel making which must be made up by increased use of scrap.

The rapid extension of steel producing as compared with pig iron producing capacity was due to the war demand for steel rather than for iron, whilst steel works and rolling mill plant could be more rapidly erected under war conditions than blast furnaces. The balance between the pig iron produced and required was adjusted by restricting the use of non-steel making iron, of iron for export, by imports of large quantities of pig iron from America, and by the increased use of scrap.

There is, therefore, at the present time, in many plants of this country, a deficiency in the supply of coke-oven and blast-furnace gas available, and this in itself necessitates the use of extraneous coal.

Conditions on the Continent are different. Belgium, France and Luxemburg possessed even before the war, comparatively modern units, using largely the basic Bessemer process (which in itself requires much less fuel than the open-hearth process), with plants laid out practically on green field sites, allowing of the fullest possible advantage being taken from the outset, of the most modern methods then available.

Under pre-war conditions, plant and fuel efficiency was naturally higher than in this country, whilst since the war, with money available as " reparations " and with the aid of profits made under low valuta conditions, the iron and steel producers of these countries have been able to bring their producing units to the highest state of perfection.

In Germany, profits made during the inflation period were devoted largely to modernisation of plant, whilst at the same time much of the fixed capital charges on the works were wiped out so that German industrialists have been able to modernise their plants completely without the heavy interest charges which British industry has to face.

In this country, on the other hand, with high capital charges on plant erected during the war, with increased cost of materials and transport, high taxation and charges for social services, the iron and steel industry has not been able to find the capital required to meet the post war conditions.

Despite these difficulties, however, marked progress has been made in the direction of reduction in fuel and other costs. As indicative of this, the price of iron and steel products has been reduced in July to a figure of 118.0 compared with 100 in 1913, and with a figure of 141.8 for all commodities.

Fuel economy has been effected not so much, perhaps, by the adoption of expensive new plant, but by more scientific control of the plant and processes involved, so as to obtain the highest efficiency from these.

The factors affecting fuel consumption in iron and steel practice are complicated, but can be generally summarised as:—

(1) Character of materials used.
(2) Character of products made.
(3) Character of process.
(4) Character of plant.
(5) Output of plant in proportion to capacity.
(6) Scientific fuel control.

(1) Character of materials.

In every phase of iron and steel practice, character of materials used is a factor of ultimate importance in the fuel economy of a process. In this connection, the finished product from one process is the raw material for the next. Thus quality of coke (an artificial product) is of primary importance for the blast furnace, the character of the pig iron made determines the economic efficiency of the steel-making process, the character of the ingot plays an important part in the efficiency of the rolling process, and so on. Whilst economic considerations predominate in every case, it is essential that all the raw materials—coke, ore and limestone and even air for the blast furnace; coal for the producer plant; molten metal, scrap and so on for the open-hearth process—should be of a character to obtain the greatest efficiency. Particular attention is being devoted at the present time to physical characteristics of raw materials used, particularly in blast furnace work, and in a number of plants economies have been obtained by:—

(1) Improvement in the physical characteristics of the coke by suitable preliminary treatment of the coal used.

(2) Screening of the coke prior to charging into the furnaces.

(3) Breaking of the larger lumps of ore and limestone.

(4) Grading and sorting of the ores and limestone.

(5) Suitable methods of charging into the furnace so as to secure the greatest possible uniformity of distribution of the burden in the conditions.

The factor of greatest importance is undoubtedly uniformity, and in this connection it is frequently overlooked that the greatest single constituent charged into the blast furnace is air. Mr. E. H. Lewis,

in a recent paper to the Iron and Steel Institute, states that the weight of air used per ton of pig iron in Scottish practice is 10 cwts. more than the total weight of all other materials charged, and variation in the moisture content in the air at Wishaw indicated differences equivalent to approximately 90 lbs. of water per ton of pig iron. To meet these variations, a silica gel plant for drying blast has been successfully in operation for several months, with resulting increase of output of between 12 and 17 per cent. and a saving in fuel of the order of 5 per cent.

In the open-hearth plant, the quality of pig iron is important. Much of the natural pig iron produced in this country is high in silicon, which has to be eliminated in the mixer or open-hearth furnace, with increased fuel and other costs. By adjustment of the character of the ores charged and careful control of the blast furnace operation, low silicon iron is being consistently produced at some British works with consequent improvement in open hearth efficiency.

In the gas producer plant, the character of coal charged has a most important bearing on the character of the gas made, which in itself is the raw material for combustion in a number of furnaces.

Frequently, the cheapest coal is not necessarily the most economical, but the whole question of character of materials used in the various operations is of such importance that it demands individual study in every case, as conditions differ so that no individual rule can be laid down, except that the vital need in every process, as far as possible, is the greatest uniformity that can be obtained.

(2) Character of products.

Table No. III. indicates the influence in blast furnace practice of the character of the products made on the fuel required; fuel consumption for foundry and forge iron and for alloys for example, all other things being equal, is considerably higher than that of basic iron. In the manufacture of steel, special steels require higher fuel consumption than steels of common quality, whilst similar considerations apply in the finishing departments.

In this connection the specialistic character of many of the products of the British iron and steel industry necessitates in itself a higher fuel consumption than would be required by products made on mass production lines by Continental producers.

(3) Character of process.

There is a fundamental difference in the fuel requirements of the Bessemer as compared with the open-hearth process of steel production.

This question was recently dealt with in the Fuel Economy Review of the F.B.I. for 1927, and the fuel requirements for the production of open-hearth steel were given as follows, in terms of therms per ton of finished steel (one therm=100,000 B.Th.U.'s).

BLAST-FURNACE AND COKE-OVEN GAS.

	Therms.	Therms.
Total therms in coke-oven gas produced		90.75
„ „ „ blast-furnace gas produced		185.00
		275.75
Required for heating coke ovens	41.25	
„ „ auxiliary coke-oven plant	20.00	
„ „ blast-furnace stoves	45.00	
„ „ blowing	12.00	
„ „ auxiliary plant	5.00	
	——	123.25
Net heat in blast-furnace and coke-oven gas for steel works per ton of pig ...		152.50

FUEL REQUIREMENTS PER TON OF FINISHED STEEL (OPEN-HEARTH PROCESS).	Therms.
Mixer	10
Open-hearth plant	48
Power for auxiliary steel work plant	2
Soaking pits and wash heating furnaces	20
Rolling mills	25
	105
Surplus	47.5

This estimate was based primarily upon the figures submitted by Mr. B. Talbot in 1918, of a works producing 6,000 tons a week of finished sections, using 23 cwts. of coke per ton of pig iron, using 80 per cent. liquid metal and 20 per cent. scrap in the open hearth, and yielding one ton of finished material per ton of pig iron.

The figures assume modern coking plants yielding 6,000 cu. ft. of gas surplus per ton of coal carbonised, blast furnace stoves operating at 75 per cent. efficiency, blowing, power and rolling mill plant operated by gas engines equipped with waste heat boilers and working on a 30 per cent. efficiency, and with steel works furnaces of modern design. Further, it is assumed that the whole of the gas is cleaned.

In the basic Bessemer process, conditions are entirely different. The production of finished steel from pig iron varies from 75 to 80 per cent. of the pig iron produced, and if 80 per cent. yield is assumed 1.25 tons of pig iron is required to produce one ton of finished steel, so that instead of a surplus of coke oven and blast furnace gas of 152.5 therms, there are $152.5 \times 1.25 = 190$ therms per ton of finished steel.

On the other side of the balance sheet, the heat requirements of the basic Bessemer plant are as follow:—

		Therms.
Coke oven and blast furnace gas available		190
Required—Blast for Bessemer plant	6.0	
Mixer	0.6	
Soaking pits	2.0	
Reheating furnaces	10.0	
Power for rolling	25.0	
Miscellaneous	5.0	
	——	48.6
Surplus		141.4

Whilst, therefore, there is in the open-hearth process, an apparent surplus of 47.5 therms per ton of finished steel over the heat available in a completely balanced plant, there is in the basic Bessemer process, a surplus of 141.4 therms. If working hours of blast furnaces and steel plants are taken into consideration, the advantage of the basic Bessemer process from a point of view of fuel consumption is further increased. In normal practice, blast furnaces work for 164 hours a week, whilst the mills operate only for 130 hours or less, depending on the frequency with which the rolls are changed.

On a 6,000 tons per week plant, using the open-hearth process, there are approximately 5,580 therms surplus per hour from the coke oven and blast furnace gases, whilst 4,840 therms per hour are required for the steel works. There is, therefore, a margin of only 740 therms per hour available, approximately 16 therms per ton of steel, so that even assuming that a completely balanced plant was available, with coke ovens of sufficient capacity to produce the whole of the coke required, the works equipped with absolutely modern power producing plant, stoves, mills and so on, and operated under conditions making for the most efficient fuel control, the margin in any open-hearth steel works between the available fuel and that required, is not great.

In addition the fuel for calcining kilns, locos, workmen's fires, power for gas cleaning plant and so on will have to be added, so that when these requirements are satisfied an additional fuel supply of raw coal would be necessary.

Further, the calculations are based on operation at practically full capacity with little loss of time due to changing of rolls, and day and night shifts, operating at similar rates of working. Unfortunately, British works producing a considerable variety of products cannot operate under these ideal conditions, and as a general rule, even with the most modern plant, there is not sufficient surplus power and gas available to meet the fuel requirements of the works, and additional coal must be supplied.

In the basic Bessemer process on the other hand, on a plant producing 6,000 tons of pig and 4,800 (80 per cent.) of finished, and assuming 164 hours blast furnace operation and 130 hours rolling, there is a surplus per hour of about 3,400 therms, so that there is an ample margin between the fuel available and required.

Despite developments in the last few years, therefore, the estimate of Mr. Talbot that 33 to 35 cwts. of coal are required per ton of finished products in a works using 80 per cent. pig in the open-hearth process, still represents practice which is probably as good as can be obtained under the conditions specified.

The fuel consumption, of course, would be different with different percentages of scrap and would be reduced as the proportion of scrap increases.

In the basic Bessemer process, assuming that the coal figure is that of clean dry coal delivered at works and that a rich ore burden is used, it is possible to produce a ton of finished material with less than 30 cwts. of coal, and, if full credit be taken for surplus coke-oven and blast-furnace gas available for outside purposes, a net coal consumption is possible of less than 25 cwts. per ton of finished steel.

In view of the fundamental difference between the fuel requirements of the basic Bessemer and open-hearth processes any comparisons between British and Continental works are impossible, unless complete analysis is made of the fuel requirements at every stage of the process, and only those items of plant taken into consideration which provide a suitable common basis.

(4) Character of plant.

The general character of engineering and power plant for the best fuel efficiency has been discussed by Mr. J. E. James in Chapter 5, whilst the fundamental principles of metallurgical furnaces have been treated by Mr. R. J. Sarjant. Certain general principles, however, can perhaps be touched upon.

A primary consideration in all iron and steel practice (except in the case of certain low-temperature processes, such as annealing, heat treatment and so on) is the high temperature at which the operations are carried out. This implies that the gases leaving the zone of highest temperature carry with them a considerable amount of sensible heat, which can be recovered by:—

(1) Absorption in the stock or metal heated; or

(2) Abstraction with regenerators or recuperators.

The blast furnace is an example of the first type, in which the descending stock absorbs to a considerable degree the sensible heat in the ascending gases from the hearth. In comparison with other metallurgical furnaces, the fuel efficiency of the blast furnace, after allowing for the carbon required for the chemical reactions, is comparatively high.

In other cases, as for example in in-and-out furnaces, the sensible heat in the gases leaving the hearth has to be recovered by regenerators or recuperators with or without subsequent use of waste heat boilers, and the actual thermal efficiency of the furnace itself is generally low. In the case of all metallurgical furnaces the proportion of fuel which *has to be consumed* to meet radiation and external cooling losses, is considerable. Expressed in terms of B.Th.U.'s radiation and external cooling losses may sometimes not appear serious (in the blast furnace for example, 10 to 15 per cent. of the heat value of the fuel burnt), but the actual quantity of fuel that must be consumed to meet these losses may be considerable. It can, for example, be calculated that in small blast furnaces 25 to 30 per cent. of the fuel reaching the hearth is expended in meeting radiation and external cooling losses from this particular zone.

In the case of other metallurgical furnaces, for example, open-hearth furnaces, radiation and external cooling losses are considerably greater than those of the blast furnace, and the thermal efficiency of good average plants will probably be only 10 to 20 per cent.

The first obvious necessity of metallurgical practice is to reduce radiation and external cooling losses, as far as possible. This implies efficient heat insulation, but a number of problems are involved in this direction. It is frequently impossible to adopt insulation in zones of highest temperature, as in the hearth of a blast furnace or in the roof of an open-hearth furnace. In fact, in these cases limitations of refractories available have necessitated the adoption of water cooling, with the result that additional fuel has to be consumed. Thus it can be calculated that in blast furnace practice, the external heat losses in the hearth zone may be increased in some cases by water cooling by as much as 50 per cent. with a resulting increase in fuel consumption equivalent to 2 to 3 cwts. of coke per ton of pig iron. It might perhaps be argued that water cooling by maintaining blast furnace lines, reduces fuel consumption and at the same time reduces repair costs, but theoretically, this course could be best accomplished by a refractory which would withstand conditions better than those at present in use. If such an ideal refractory could be discovered, not only would the heat losses at present involved by water cooling be reduced, but possibilities would be opened up of heat insulation. This has already proved extremely successful in the case of heat treatment furnaces when temperatures are not too high, and in such cases 25 per cent. fuel saving has sometimes been obtained. Similar possibilities exist in blast furnace stove practice and in such portions of the open-hearth furnace (regenerators for example) where temperatures are not excessive.

Regeneration.

Another field which is at present the subject of close investigation is improvement in regenerator efficiency. In blast furnace stove practice, the adoption of improved methods of stove filling such as "Semmelsteine," spiral bricks and so on, has allowed of an increase in stove efficiency of as much as 15 per cent. In open-hearth furnaces, increased regenerative capacity, together with specially shaped bricks, has in the more modern furnaces considerably improved their efficiency, but problems in this case are not so easy of solution as in stove practice, owing to slagging difficulties.

Further, in this country, difficulties are frequently experienced in obtaining sufficient depth of foundations of regenerators, and it is therefore not possible to get adequate height to allow of optimum regeneration. The average height of regenerators in this country, would be in the neighbourhood of 14 to 15 feet, and the temperature of the regenerated air 1,100° to 1,200° C. In some works, these figures are exceeded, but in no case have temperatures been noted of 1,500°, which are being obtained in some of the Continental plants where facilities allow of the employment of very deep regenerators with special types of filling, or of supplementary regenerator chambers.

In many works in this country, waste heat boilers have been installed in connection with open-hearth furnaces, which recover to some extent the heat lost owing to insufficient regenerator capacity, but these are not a complete solution of the problem, as the temperature of the regenerated air and producer gas still remains lower than would be desirable for the greatest speed of furnace operation.

Efficient regeneration implies high temperature of regenerated air and gas, rapid combustion, a fast working furnace of high fuel and productive efficiency, and there appears to be room for investigation into the question not only of suitable regenerator filling but of design and size of regenerators for different furnaces.

Optimum size and design of plant.

It has been stated that the minimum capacity of a completely balanced works to secure the best efficiency should be at least 300,000 tons of finished products per annum. The Continental experts, however, consider that this figure is too low, and that it should be 500,000 tons, whilst the more modern Continental plants such as Hamborn, have a capacity of considerably more than 1,000,000 tons per annum.

Where specialistic products, however, are produced, works of such capacity would probably not be as economic as smaller works, and the question of size and design of plant is one which must be studied for every individual case.

In the case of blast furnace practice, a study of American and Continental results indicates that large modern fast driving furnaces operate more efficiently than small furnaces, due to a great extent to the lower radiation loss per unit of product.

Against this, very small furnaces (Scottish furnaces, for example, making 60 to 70 tons of pig iron per day) operate with remarkable fuel efficiency, probably due partly to the fact that such furnaces are not water cooled, and therefore external cooling losses are low, and partly to the greater reducing efficiency in the shaft of the furnaces owing to more prolonged and more efficient contact between the reducing gases and the ore.

In the case of open-hearth furnaces, no general rule can be laid down. Taking a bird's-eye view of practice in this country and abroad (v. Bansen, *Stahl u. Eisen*, 1925, No. 14) large furnaces, as a rule, appear to operate with better fuel efficiency than small furnaces, but there are many exceptions.

(5) Output of plant in relation to capacity.

A study of the characteristic curves submitted by Mr. H. C. Armstrong (Chapter 6) indicates the important influence of operating metallurgical furnaces at highest capacity. In this direction, Great Britain is handicapped to some extent by the specialistic character of many of the products produced, so that mass production on modern lines is difficult. Considerable assistance has been given, however, by the British Engineering Standards Association. The reduction in the number of standard sections made by them has increased productive capacity considerably, whilst further steps that have been suggested to assist, are the formation of Export Sales Associations for the distribution of various groups of products in the industry which are more or less uniform in character and the allocation of orders for particular products and sections to works possessing facilities for their production in mass, leaving the smaller units to deal with the more specialistic products.

(6) Fuel control.

Methods of fuel control in different sections of the industry have been dealt with by specialist authors in subsequent chapters, and the factors involved need only be summarised generally :—

(1) *Measurement of Fuel used in Relation to Output.* Marked economies have been obtained in all British works where suitable measuring apparatus for fuel has been installed, and a number of firms are now making use of the service of special officers whose function is to measure fuel used in the different units, to collate the results obtained and to suggest methods of increasing thermal efficiency.

In this connection, fuel measurement implies not only a knowledge of the actual quantity of fuel used in any particular unit, but also a knowledge of its quality, and in most cases the first result of the inauguration of any system of fuel control is the realisation of the necessity for standard quality of gas or solid fuel used. This is particularly important when producer gas is used, as air and gas regulation is impossible unless gas quality is uniform.

The next step, when gaseous fuels are used, is to maintain constancy of pressure in the fuel gas. With blast-furnace and coke-oven gas the most effective means of obtaining this end is by the installation of gas-holders, which have been installed on the Continent up to 11,000,000 cubic ft. capacity. In some cases twin holders of approximately $3\frac{1}{2}$ million cubic ft. capacity have been erected for storing coke oven and blast-furnace gas, to supply mixtures of these gases of suitable composition to open-hearth and other furnaces.

In producer gas plants, constant pressure can be obtained by automatic pressure regulators working in adjustment with air and steam supply, so as to obtain gas of uniform quality of constant saturation temperature and constant pressure. The advantages of uniform gas and air pressure are considerable, and in certain cases, particularly in stove practice, marked improvements in thermal efficiency have been obtained.

Storage of surplus fuel and energy.

Systematic measurement of gas, steam and electrical energy used in iron and steel practice indicates the considerable variations that occur in demand for power and fuel at different periods. The possibilities involved by levelling peak periods are interesting. There are two aspects of the problem to be dealt with, namely :—

(1) Storage of energy and fuel available during periods of low demand in working shifts (for example, when rolls are changed and so on).

(2) Storage of surplus week-end blast furnace and coke oven gas.

The storage of energy produced during mid-week slack periods is comparatively simple and can be done by means of :—

(*a*) Gas-holders; (*b*) steam accumulators ; (*c*) heat storage in blast furnace stoves.

The advantages of such systems are :—

(1) Reduced loss of output owing to inadequate steam.
(2) Reduced steam consumption with consequent saving in fuel.
(3) Reduced number of boilers required.

Suitable systems of heat storage have frequently been able to save 15 per cent. of fuel under favourable conditions.

The storage of surplus blast furnace and coke oven gas during the week-end is a big problem, owing to the enormous volumes that have to be dealt with. In some works in this country, blast furnace gas available during the week-end is used to keep mixers and open-hearth and other furnaces hot, so as to allow restarting as quickly as possible. This however, is only a partial solution of the problem, and in certain districts it might be desirable to consider the possibilities of using surplus week-end energy in the iron and steel works, for public power supply purposes. This is already done in some of the Continental districts, and in Lorraine, for example, a number of works and mines have combined to form " La Siderurgie Lorraine " for the purpose of using to the greatest advantage, electrical current available from each of the component works, the surplus being used for public supply.

National work on fuel economy.

During recent years, an attempt has been made to co-ordinate nationally, the work that is being done on fuel economy by individual iron and steel producers in the country. In 1923, a Fuel Economy Committee was formed by the National Federation of Iron and Steel Manufacturers for the purpose, as far as possible, of effecting a liaison between the different producers in this direction. Apart from collating and distributing records of fuel consumption throughout the industry, this body has, with the support of the Fuel Research Board and the assistance of the Universities of Sheffield, Newcastle and Glasgow, formed a series of local coke research committees, which are at present investigating coke problems in the respective areas. At the same time, research has been initiated at the Imperial College of Science and Technology, on the fundamental aspects of blast furnace phenomena, an investigation which promises to be of considerable importance.

As the result of the work of the coke research committees, it appears likely that a standard method of coke testing will be established in the near future. Differences in the quality of cokes from different areas are well appreciated by blast furnace operators, but there has been difficulty in the past in devising a method of testing which would allow of a quantitative determination of these differences in the laboratory. A number of tests have been studied dealing with such properties of coke as porosity, reactivity, hardness, resistance to abrasion, combustibility and resistance to shatter, and out of the data that has been accumulated, it appears likely that in the near future a standard method of testing will be evolved which will indicate to the blast furnace and coke oven managers the value of coke for smelting purposes. At the same time, these investigations are correlated with others on such fundamental properties as coke structure, reactivity and so on, which are being conducted in collaboration with the Fuel Research Board.

Methods of improving coke quality are being studied and the influence of blending of coals, period and temperature of carbonisation, oven width and design, etc., are at present under investigation.

Other aspects of fuel control in works practice are dealt with by local fuel committees formed in different producing districts for the purpose of considering specific fuel problems in these districts. These committees work on somewhat similar lines to those described by Dr. K. Rummel (page 17), but developments in this country have not yet proceeded as far as those in Germany.

The work already done and confirmed by the experience of the "Warmestelle" (Heat Economy Bureau) of the German iron and steel producers, indicates clearly the advantages of co-operative effort in the investigations of fuel problems, and the technical and economical possibilities involved in their solution.

Chapter 2.

FUEL ECONOMY IN THE BLAST FURNACE.

By J. E. Fletcher, M.I.Mech.E.

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There is some ground for taking new view-points from which to examine the fuel consumption per ton of iron yield in the blast furnace, for, whilst recognising the assistance given by Gruner and Johnson, together with the scientific importance of the study of equilibria in the blast furnace gases, the attempt to formulate definite and final laws for the guidance of the blast furnace engineer has not yet been successful.

After considering the statements, theories, and empirical conclusions of recognised authorities, the blast furnace economist is led to ask very seriously, a number of practical questions, among which the following may be regarded as typical:—

1st. What influences are brought to bear on the air blast as it ascends from the tuyere level to the horizon of maximum temperature?

2nd. What is the gas composition in the portion of the coke mass, lying between the tuyere level and that of maximum temperature?

3rd. What are the carbon and gas reactions above the fusion zone, assuming that the gases passing into the reduction zone are CO and N_2?

4th. Do the analyses of the throat gases provide any real index to the character of the reactions in the zones lying between the tuyere and metal-melting horizons and those higher in the shaft wherein the major portion of reduction is taking place?

5th. How are the reactions in the two zones affected by rate of driving and velocity of the ascending gases? In what way are these two-speed functions reflected in the throat gas analyses and in the coke consumption?

An examination of cupola operation, in relation to fuel economy, has forced the writer to recognise the effect of melting speed per sq. ft. of hearth area (at tuyere level and at the melting horizon), and of the rate of coke carbon consumption relative to speed of melting. These two functions—metal melting and coke-carbon gasification—are of course dependent upon the air supply, and there would appear to be little doubt that there is an optimum rate of carbon consumption, per sq. ft. of cupola area at tuyere level, for each size of cupola. The top gases have an analysis which indicates whether this optimum has been reached or exceeded.

It is from this standpoint that the writer has sought to approach the blast furnace problem.

As the air blast ascends from the tuyere level to the horizon of maximum temperature it traverses the voids between the coke lumps, coming into contact with the descending streams of metal and slag. If the blast is cold as it leaves the tuyere mouth it is clear that heat is abstracted by the air from the incandescent coke and from the liquid metal and slag streams. Some time must elapse and a distance traversed before the air reaches a temperature sufficient to commence the gasification of the coke carbon.

In the cupola, before the metal has reached the tuyere level, the air may travel inwards 9 or 12 inches and ascend 10 or 12 inches before the oxygen has completely reacted with the carbon, the shape of the lining (internally) affecting the distance traversed. It is significant that the distance traversed before all the free oxygen has disappeared, when the metal is flowing past the tuyeres, is apparently about three-tenths of the radius of the bore, and corresponding with about half the cross sectional area of the cupola bore. When the air has traversed the outer annulus of the cupola section (50 per cent. of the cross section), and has ascended some 10 or 12 inches, the level of maximum temperature appears to have been reached, and it is evident that in the outer half of the section a large percentage of the metal is melted. The trickling metal and the incandescent coke in this annulus may, therefore, be considered to have been, in the main, the means by which the air has been preheated. The more rapidly the metal is melted the lower as a rule, is the horizon of maximum temperature, and the greater the economy resulting from the pre-heating of the metal and coke in the cupola shaft.

Below the tuyere level the metal + slag + coke mass is not kept hot by the combustion of carbon, though some little combustion may take place there, but must be mainly due to the heat absorbed by the coke from the metal and slag traversing it from the upper and hotter horizons, together with radiated heat from the zone of combustion. Clearly, the preheating of the blast above the tuyere level is greatest when the hot fluid metal and slag are flowing rapidly, the measure of preheat being expressed in terms of the weight of fluids traversing each square foot of hearth or bosh area, per unit of time. This conclusion is based on the assumption that the coke lumps washed by the streams have a certain size and that the passage area through the voids bear a fixed proportion to the total hearth or bosh area, whichever horizon is being studied. Theoretically, the smaller the coke lumps the more rapidly will the coke be heated by the metal and slag streams—but there is probably a critical size where the resistance to stream flow prevents further increase of heat conductance.

Again, the air streams ascending from the tuyeres will absorb less heat per foot of ascent as the velocity is increased, hence the higher the tuyere stream velocity the lower will be the degree of blast preheat per foot of ascent—dependent of course upon the initial temperature of the blast, and on the length of air stream trajectory per foot of ascent.

The weight of air and fluids penetrating each square foot, per minute, at any given horizon above the tuyere level, in counter-flow fashion, will, therefore, control the position of the zone of greatest temperature, which, it will be seen, is not a perfectly horizontal stratum. The air streams nearest to the tuyere outlets will be the coolest and lowest in velocity, and will be affected by the wall radiation, hence will rise higher before attaining the necessary temperature for maximum intensity of combustion.

Carbon-oxygen reactions.

Reverting to the differences in the carbon-oxygen reactions in the outer annular half of the hearth area and in the central half of the cupola section. The same differences are recorded by Kinney, Royster and Joseph in their paper on iron blast furnace reactions (U.S.A. Bureau of Mines, 1927). In the furnaces cited, the great changes in the CO/CO_2 ratio occurred in the locality of the inner ring of the annulus, enclosing half the cross section of the furnace, between the tuyere horizon and the one 27 inches above it.

Indeed, the mean gas analyses in the outer annulus and the inner ring, when compared, show the differences in the two halves of the furnace section in a very marked fashion. The approximate values are given below:—

Position of horizon.	In outer half.			In central half.		
	CO_2 %	CO %	CO/CO_2	CO_2 %	CO %	CO/CO_2
63 feet above tuyeres	11.5	26.0	2.26	7.0	31.0	4.43
53 feet do.	13.8	23.8	1.73	9.0	29.0	3.22
42 feet do.	11.0	27.5	2.50	6.0	31.0	5.16
19 feet do.	1.2	31.7	2.64	1.2	31.7	2.64
27 inches do.	10.0	24.0	2.40	0.6	43.7	73.00
At tuyere level	10.0	2.0	0.20	1.8	43.7	24.30

The violently changing reactions taking place between the tuyere level and the horizons 2 or 3 feet above it, are significant. There is not a great deal known about the reactions within these lower horizons, but the graphed results of Rhead and Wheeler's determinations of the CO/CO_2 values (equilibria) at temperatures between 850° C. and 1,200° C., at a pressure of 1 atmosphere, show how rapidly these values increase after 950° C. has been reached, and also how, as the gas pressure is increased, the ratio decreases. In the gasification of coke by a dry air blast, the sensible heat liberated may be largely dissipated by radiation, through the cooled hearth walls of a blast furnace or cupola before the resulting gas reaches the place where it is utilised. But, if there is present in the coke mass a moving or flowing material, like liquid iron or slag, some of the sensible heat may be absorbed by such metal or slag. The greater the flow of metal or slag through the coke (as expressed in lbs. per square foot of hearth area, per unit of time) the better will be the opportunity for such metal to absorb the sensible heat liberated, coke economy

resulting. In a blast furnace or cupola hearth, the voids in the coke may not exceed 20 to 30 per cent. of the hearth area and the velocity of the gases through the voids may reach 100 feet per second in the outer half of the hearth area, at the horizon of maximum temperature.

At so high a velocity, perfect equilibrium between CO and CO_2 may not be reached, but in the central half of the hearth area the high CO/CO_2 ratio indicates that, at the slower gas velocities there, the theoretical equilbrium is attained very rapidly, even at the tuyere horizon or a few inches above it.

Fuel economy factors.

From the above considerations the question naturally arising is: Is the type of reaction operating in the outer annular half of the hearth or well area, productive of greater fuel economy than that which operates in the central half, where the gas velocities are lowest and where the rate of smelting is appreciably less than in the outer zone?

Another equally important question, following from the study of the influence of fluid metal and slag in the coke voids, is: Is there an optimum rate of driving (dependent probably upon the size of the hearth, shape of lining and height of furnace) which is productive of the highest possible fuel economy for a certain type of burden—the physical and chemical composition of which is reasonably constant for each ingredient?

Again, another factor affecting economy is associated with the presence of coke ash and slag in the coke mass contained in the stratum of material lying between the tuyere level and the horizon of iron melting. The iron melts before the ash in the coke liquefies, the levels at which these two melting actions occur being some distance apart. The ore gangue, liberated from the reduced iron, must also descend to a level considerably below that of iron melting. The gangue slags, containing the flux oxides, will flow over the coke lumps at the same time as the coke ash is liberated by combustion of the coke. The resulting mixture of gangue, flux oxides, iron oxides and coke ash is, or should yield, a slag of such composition as, in contact with the molten driblets of iron, will bring about the alloying of the iron with silicon, manganese, phosphorus and sulphur.

The writer has long regarded the slag reactions in the tuyere region or below it, as responsible for the alloying of the iron in much the same way as in the gas-agitated slag blanket of the open-hearth steel melting or refining furnace. The intimate contact of the metal and slag streams within the coke voids, in the zone of maximum temperature, blown and agitated by the ascending hot gases, is obviously an ideal condition for the alloying actions.

The oxidation of the coke ash, covering the coke lump surfaces in a manner dependent upon the character of the pores and on the percentage of ash in the coke, must affect the carbon-oxygen reactions and retard them, more or less, thus destroying the desirable employment of the sensible heat liberated when hot dry blast gasifies the coke carbon. Korevaar's notes on the heat absorbed in the fusion of coke ash (disputed by some) would seem to be correct, the effect of high ash percentages being more responsible for high coke consumption than is usually accepted. The alloying actions above referred to may conceivably occur, and probably do so, in the region of maximum temperature some inches above the tuyere level, where there is intimate contact between the coke, ascending hot gases, and the slag and metal streams. The heat exchanges involved in the slag reactions, and occurring in this zone, must affect the gaseous reactions, and here again, as these heat exchanges take place in the coke voids, the velocities of gas and flowing metal, taken in relation to the bulk of metal and slag flowing into the hearth, must affect the coke consumption values.

It is clearly evident that the influences above described, and which are brought to bear on the air-blast as it ascends from the tuyere level to the horizon of maximum temperature, must very considerably affect the fuel consumption of the blast furnace and cupola.

Horizon of maximum temperature.

From the foregoing it would appear that the position of the horizon of maximum temperature is of great importance. The control of this level consists in the regulation of the flow of metal, slag and

gases (weight passing through each square foot of hearth or bosh area, per unit of time), so that the carbon is burnt to CO at the level of maximum intensity of combustion. This level or plane may be looked upon as the grate of the furnace, which should be approximately constant, and on which the coke charges melt the iron, fuse the slags, and bring about the necessary alloying actions. The coke mass below the iron melting level in the blast furnace corresponds to the bed coke of the foundry cupola.

It does not appear possible to arrive at the exactly correct rate of coke consumption, per sq. ft. of hearth area, per hour but, as the result of experience, it is possibly connected with the chimney draught action of the furnace shaft, which should be sufficient to carry off the products of combustion at the maximum temperature level or grate of the furnace, when assisted by the blast pressure necessary to penetrate the burden column. The rate of coke consumption in the blast furnace per sq. ft. of hearth per hour must also be related to the rate at which the iron can be smelted before excessive direct reduction by carbon in the hearth zone takes place.

Attention has already been drawn to the rapid alteration in the gas analyses at the tuyere level and in the two or three feet of coke, immediately above it (Kinney, Royster and Joseph). Some light has been thrown on this detail during the examination by the writer of cupola gas analyses in the melting zone.

In the cupola, the weight of coke burnt, per sq. ft. of hearth area (at tuyere level) per hour is often about 150 lbs., the air supply per lb. of coke being, approximately, twice that required in the blast furnace. In a typical example of modern cupola practice it was found that at the tuyere level or immediately above it the CO/CO_2 ratio was about 1.3, 21in. above this the ratio was 1.5, falling to 1.0 at about 5 feet above the tuyeres. At about 7 feet above the tuyeres the ratio fell to 0.3, rising to 0.7 at the top of charge (14.5 feet above tuyeres).

In the same cupola, adjustment of the air supply considerably affected the CO/CO_2 values, but the horizon, corresponding with a maximum CO content, was constant at about 4 feet above tuyere level. The horizon corresponding to a maximum CO_2 content was 7 feet above tuyere level. An immediate reduction in the CO/CO_2 values took place, following the attainment of the maximum values at the horizon, 4 feet above tuyere level during a series of modifications of the blast supply. This interesting result is a parallel to that recorded by Kinney, Royster and Joseph (see table, page 5), where in the central half of the furnace the maximum CO/CO_2 value drops rapidly from 73.0 at 2ft. 3ins., to 2.64 at 19ft. above the tuyeres. It is unfortunate that gas analyses were not taken at levels, say 4ft. and 7ft. above the tuyeres, as these would have shown the location of the level at which the sudden change in the CO/CO_2 ratios takes place in the blast furnace. It would seem to be the horizon at which the fusion of the metal takes place (say 1,140° C. to 1,200° C.) in the central half of the furnace. In the cupola the level of the change point is raised when high phosphorus iron is being melted, and lowered when irons low in carbon, silicon and phosphorus (high melting point) are being melted, the latter melting lower in the furnace. When no metal is being melted and the furnace is functioning as a coke-gas producer the level of the change point is nearer to the tuyere level and is then controlled by the volume of air supplied per sq. ft. of hearth area per unit time. In the cupola the analysis of the top gases is related to the amount of preheat given to the descending coke and metal, and to the sensible heat in the gases set free at the horizon of greatest temperature.

Here again, the speed of melting is associated with fuel economy, provided the amount of sensible heat in the ascending gases is high by suitable air control. In the cupola example given previously, the adjustment of air control brought about CO/CO_2 values in the top gases, varying from 1.33 to 0.64. At 1.33 the coke consumption, per ton of iron melted was 2.5 cwts., at 1.0 it was 2 cwts. and at 0.64 it was 1.6 cwts. In thus comparing the somewhat parallel problems of the cupola and blast furnace the writer has attempted to lead the student of blast furnace practice along lines which may be practically suggestive. He had hoped to present the results of his comparisons of blast furnace top gases with the reactions in the hearth and shaft, as influenced by slag, coke ash, and flux, together with the influence of rate of driving, but the problem is so complex when these variables are involved that consideration of their influence must be deferred, pending completion of researches now in progress.

Chapter 3.

THE OPEN-HEARTH FURNACE.

By W. J. Brooke.

The open-hearth furnace, regarded as an apparatus for the efficient utilisation of gaseous fuel, can hardly be termed a success, and it is not difficult to understand the reason for many of the attempts which have been made to improve its efficiency. Speaking generally, little progress has been made, since the first introduction by Siemens, of a furnace for the manufacture of molten steel.

It is by no means beyond the powers of our heat engineers to design a combination of gas and air ports to produce a high state of efficiency and combustion. The chief difficulty arises from the fact that, with the regenerative system at present in operation, a furnace block designed to give the highest efficiency in combustion is not capable of dealing with the products of combustion at the outgoing end. Attempts have been made to overcome this difficulty, with more or less success, but it is safe to assume that, at the present time, the large majority of open-hearth furnaces in this country are of the character that has become familiar to us during the past forty or fifty years.

The problem of producing a ton of steel, with the lowest possible expenditure of fuel, either solid or gaseous, is one that would appear to divide itself into three sub-divisions, viz.,

(1) Quality of gas,
(2) Output, and
(3) Efficient utilisation.

Seeing that in this country, at the present time, the gas producer is, practically, the only means employed for the production of gaseous fuel for steel furnace practice, it naturally follows that the efficiency of such a plant is of primary importance.

Quality of gas.

Theoretically, nothing can be easier than the principle of producing gas from coal. A suitable mixture of air and steam is passed through a bed of incandescent coke, whereby a combination of carbon monoxide and hydrogen is produced, together with small quantities of hydrocarbons and tar vapours, from the destructive distillation of the raw coal, when first charged on the existent bed of incandescent coke. In practice, the difficulties surrounding the production of really good gas are many and varied, owing to the variability of the qualities of coal available commercially, which themselves introduce many complications, and, also, largely owing to the difficulties surrounding the human element engaged in controlling the plant.

The latter difficulties have engaged the attention of engineers for some years past, with the result that, nowadays, a really modern gas producer is practically automatic and requires very little assistance in practical administration, from the personnel controlling the plant, in fact, one may reasonably affirm at the present time that almost all the difficulties surrounding the production of producer gas in the early days have been surmounted, and the modern steel plant can rely upon a regular supply, and a constant and uniform quality of gas. This condition is one that is absolutely essential, before one can attempt to apply scientific control to its subsequent utilisation.

It will be within the recollection of many steel makers of years' standing, that the difficulty in obtaining satisfactory outputs of steel, with a low consumption of fuel, was largely caused by the great fluctuations in quality and quantities of gas available.

Probably, owing to the high cost of coal, questions of fuel economy in the past have received much greater attention from Continental engineers, than has been the case in this country. The premier position of Great Britain, as a producer of cheap fuel, is no longer so pronounced as it was one or two decades ago, and, owing to the very seriously increasing costs in this country, the question has become of as great

importance to us as it, previously, was to our Continental competitors. In fact, one may go even further and state that the position is even more important to us now than hitherto, particularly by reason of the high cost of wages, and other conditions in this country, as compared with the Continent, all of which tend to increase our costs of production out of all proportion to the resultant selling price.

A number of very efficient gas producer plants are now on the market, chiefly of American, or Continental design, and with many of these, gas can be produced efficiently and cheaply, to suit the needs of the modern steel manufacturer.

Output.

It usually follows that the larger the output of material, per unit of time, the lower will be the fuel consumed, per ton of output. Whilst this is, undoubtedly, true up to a point, it by no means summarises the whole position, and it would appear that there are still a considerable number of open-hearth superintendents who are inclined to devote their whole attention towards output, as a means of reduction of fuel costs.

Output is, at all times, of the utmost importance, since it is one of the dominating factors influencing the position, and, also, has a very large bearing on the reduction of overhead and other charges.

From observation of results obtained at a large number of British open-hearth plants it is, however, soon obvious that other factors than output have a great influence in fuel economy. An instance of this is within the writer's experience. An old-fashioned plant with hand-charged furnaces, of 30-40 tons capacity, using only 30-35 per cent. of scrap, and with an output of not more than 300 tons per week per furnace, produced ingots with a coal consumption not exceeding 7 cwts. per ton. The gas producers, in this case, were all operated by hand, and were of small capacity, gasifying 6-8 cwts. per hour. Another plant with furnaces slightly larger, i.e., 50 tons, and with an output of not more than nine charges, or 450 tons, per week, with 35 per cent. scrap and hot metal, and with a similar type of gas producer, was regularly making steel with barely 5 cwts. to the ton. Again, another plant fitted with rotating bottom producers, and using, partially, purified mixer metal, and with an output of 650-750 tons of ingots, per week, could do no better than $7\frac{1}{2}$-$8\frac{1}{2}$ cwts., per ton.

Quite obviously, output was not the dominating factor in any of these cases, and the reason for the difference had to be sought for elsewhere. This brings one to the third point mentioned, namely, efficient utilisation.

Efficient utilisation.

As further evidence of the variability in fuel consumption, per ton of ingots, reference may be made to Continental practice, where, for many years, one has been very conscious of the fact that such consumptions have been, invariably, lower than the average practice in this country. To a certain extent, this may be attributable to difference in design of furnaces, but adoption of similar designs in Great Britain has not, usually, met with the same results as those obtained on the Continent.

All this, obviously, points to factors operating, other than output, and/or difference in furnace design, and the statement may be made, with absolute certainty, that, by the exercise of greater scientific control and better education of the individual workman, results can be procured, in this country, equal to those obtainable anywhere else. To secure such results, it is desirable to reduce all unnecessary variables to the lowest possible point, and here it may be said that, it is very little use trying to make gas economically, from unsuitable fuel. The best qualities of free-burning gas coals, whilst more expensive in the first instance are, undoubtedly, cheapest in the long run, since they (combined with modern gas-making plants) contribute to the production of a gas of uniform quality and quantity.

Added to this, if we assume the adoption of a modern form of gas machine, we have attained a product in which the variables are reduced to the lowest possible point. The question then arises as to what is the best means of utilising this product, in the most efficient and economical manner.

Reverting to the statement previously made, that during the past decade or two, Continental efficiency has been in advance of that obtaining in this country, one is led to question why this is so. Instances have been given, and these are common knowledge to most people, that, notwithstanding, the adoption of Continental appliances, Continental results have not, hitherto, always been obtained in Great Britain. It would, therefore, appear that the question of personnel must be the dominating factor, and here we have to ask ourselves where this influence exerts the greatest effect.

Personnel, naturally, divides itself into two classes, those who have the power of directing influences, and those who have to carry those influences into effect, or, to express it in common language, we have managers and workmen.

Since Continental practice in the past, has been superior to that operating in this country, one might readily assume that workmen on the Continent are superior to those here, since the resultant effect of scientific design, control and progress, must leave to the workman the opportunity of carrying these resultant effects into practice.

The fact that the adoption of Continental and American practice, as regards mechanical appliances, is not in all cases giving the results that might reasonably have been expected, leads one to the belief that the translation of scientific methods into practical effect has not been conveyed to the workmen here in the same manner as has been done elsewhere, and here we are faced with a question of psychology. On the Continent, a manager has only to give an order, or to express his desires in writing, for the workmen to carry them out into absolute effect. The British character, however, is somewhat different. The British workman requires to be told the reason why: it is not sufficient to tell him to do this, that, or the other. His individualism requires that he should be made part of any project which it may be necessary to carry out, and, in so far as, the carrying out of an instruction he may receive, may differ from what he has learnt from his grandfather, and needs to be combined with something he cannot apply himself, requires very careful consideration on the part of any man, who would be a successful manager. We come, therefore, to the point that, given suitable conditions the best results to be obtained from these conditions must be covered by the extent to which the man in control is able to carry out his ideas through the medium of his workmen. The average British steel smelter is not behindhand in intelligence, in comparison with either his Continental or American rivals, neither is the average British steel works manager deficient in technical knowledge. The whole question is wrapped up in the correct adaptation of the one to the other. Psychology has been referred to, and the method by which the Continental manager can obtain, through his workmen, the results he requires, is not, necessarily, the method to be adopted by our own people. It is within the writer's knowledge of a modern plant, with appliances quite comparable with the best obtaining on the Continent, where, at one time, the fuel consumption was very high. Notwithstanding all improvements that were made on the gas production side, the results were still unsatisfactory. The mere fact of taking the first hands into the laboratory and showing them the working of an ordinary Bunsen gas burner, and explaining to them the importance of the effect of the accurate admixture of air and gas for correct combustion, eventually resulted in a reduction of 2 cwts. of coal, per ton of steel made. This course of instruction, naturally, occupied considerable time, but the fact of taking the British workman, as it were, into one's confidence, and carefully explaining to him the reasons why certain things should be done, resulted in creating in this plant, what was practically a revolution.

Following these instructions, very great pains were taken to prove to the men the value of obtaining perfect combustion as far as is possible, in an open-hearth furnace. Concurrently with these, records of actual gas consumption were made, in conjunction with various openings of air admission, at the regulating valve. Temperatures of the regenerator chambers were taken at the top and at the bottom, both on the incoming and exit sides, and, further, temperature readings were taken, and analyses made, of the flue gases at the bottom of the chimney stack. All these results were carefully tabulated, and deductions drawn therefrom. Many months were occupied in this work, and gradually, as the men began to see definite improvements accruing, their interest rapidly grew, especially as they were kept closely informed of the results obtained from the various experiments that were being tried. During the whole of this period, no alterations, whatever, were made in furnace design. Special attention, however, was directed to keeping the quality and pressure of the gas from the producers, as constant as possible.

Economic results.

On looking back, and tracing the sequence of the various operations which have led up to this interesting development, one is struck by the fact that the whole process (now that everybody is working together), is so extremely simple. The mistakes which are obvious to-day, but which were unknown previously, appear almost absurd in their simplicity. The results mentioned, are not the only ones that have accrued. The approximation to perfect combustion that is now being obtained has meant that, whilst the total coal bill for the week has been considerably reduced, the output of steel has been, equally, considerably increased, so that the final end has been achieved, by the combined process of increased output together with reduced fuel consumption.

A further remarkable result, and this, one that might reasonably be expected, has been the marked increase in the life of the furnaces, the nett result being a very decided reduction in the cost of manufacturing the ingot.

There is no royal road to learning, and it is impossible to lay down any hard and fast rules as to how such results can be achieved in every open-hearth plant. That is a matter which must be settled between the individual management and workmen at any one plant, and constitutes a really vital test as to managerial efficiency.

It is not proposed, at this point, to touch upon methods of gas making, or design of open-hearth furnaces, as it is assumed that, in a really modern works, these have already received due attention, and are, therefore, quite comparable with the best Continental and American practice. The object of this chapter is merely to draw the attention of those in control, more closely to facts which, unquestionably, receive too little attention in this country.

A word, however, may be said with reference to the system of heating open-hearth furnaces by means of a mixture of coke-oven and blast-furnace gases. This, naturally, from the very nature of things, can only have reference to open-hearth plants, which are part of the works containing both coke ovens and blast furnaces. The system has much to commend it, if only from the national viewpoint of fuel economy. Blast-furnace gas alone, is not of sufficiently high power to admit of its use in the manufacture of steel. It can be employed, however, and is, indeed, being used for the heating of pig iron in a mixer, and it is being largely employed on many works for the heating of ingots, prior to rolling in the mill. There is no doubt but that, where practicable, this combination of gases will very soon be in operation in this country, and can be employed as one of the means towards attaining that Mecca of all steel makers—the complete production of the finished steel, using only fuel at the coke ovens and blast furnaces.

It may be that, in the future, this result will be achieved by the erection of a large central station, so placed as to render it possible to pump the gas to steel works, conveniently situated for the purpose. Many economies should result from such a scheme, both in the manufacture of the coke and in the displacement of coal, in the manufacture of the ingot. On the other hand, works not so conveniently placed, may decide to erect, or reconstruct, their ovens as part of a single combined plant. In this case, the coke ovens may be heated, by means of blast-furnace gas, and the whole of the surplus gas used for steel making. This would result in a lower capital expenditure for the building of the ovens for the supply of the necessary gas, but this, and many other factors, would have to be settled in view of the particular arrangements which might exist at any one works. The modern coke oven, combined with a blast-furnace plant, and an open-hearth plant, will, undoubtedly, provide one of the greatest sources of fuel economy that has been available to steel makers, up to the present time.

Chapter 4.

METALLURGICAL HEATING FURNACES.

By R. J. Sarjant, M.Sc., A.R.C.Sc., D.I.C.

The subject matter of this chapter is confined to the sections of the subject dealing with design from the purely thermal aspect. It is an outline of the application of the fundamental principles underlying the generation and transmission of heat in the specialized sphere of metallurgical heating furnaces. There are complexities of industrial practice which, in the present state of knowledge, relegate the rationale of furnace heating, in some cases, to the domain of inspired guesswork. Furnace construction demands, not only a specialized study covering a wide field of chemical engineering, mechanics, fuel technology, the properties of the materials used, the physical laws of heat transmission and gaseous flow, but involves a sociological factor. There is not only the incidence of the usual economic questions, all the more acute because the furnace installation is, usually, only ancillary to the main industrial process and, therefore, of secondary importance, so to speak but there is the question of personnel. The degree to which special provisions and controls are installed should be a function of the skill and enthusiasm with which they are likely to be used.

SELECTION OF THE FURNACE.

It is practicable, within certain limits, to use any fuel for any given operation. The choice of the fuel is, usually, limited by its availability and economic value. Having settled this, the following guiding principles should hold:—

Adaptability and Flexibility in Output. The first function of the furnace is to give a satisfactory product, as to degree and uniformity of heating, consistent with the variations of output, and conditions which the shop imposes. This demands a definite transfer and distribution of heat. To obtain this, in the present state of knowledge of the subject, is an art.

Mechanical Stability—Ease of Control. There is a compromise between an installation, so far mechanically controlled as to be " foolproof " in operation, and a mechanism so complicated, as to require special handling and heavy maintenance charges. There are points of control which, in practice, are of great importance, such for example, as the making of all valves and controls readily accessible to the operator, at the point at which he can see into his furnace. The placing of inspection and cleaning doors is a matter falling into the same class. Robustness of construction and substantial foundations are essential.

Fuel Economy. Since the cost of fuel is a recurrent charge on the heating operation, usually far outweighing the capital charges, it follows that the fuel consumption, per unit of material heated, is a dominant factor in selection, but it happens that this is an item upon which there is most doubt, particularly as regards variation in load. For a given set of combustion conditions, there is a fixed relation, in any given installation, between the fuel consumption, the load, the dimensions of the laboratory and the temperature. There is a fixed heat input required to raise it to working temperatures, and a fixed rate of loss of heat by radiation and convection from walls and roof, and by conduction from foundations, when the furnace is maintained at that temperature. There are, therefore, readily ascertainable criteria, upon which information should be sought. As regards the operation of the load factor, a convenient means of comparison within any one class, is to base it upon the unit of heating surface, for a given increment of temperature. Thus, the output should be expressed as lbs. of material heated, per hour, per sq. ft. of heating surface, per 100° C. rise in temperature, or B.Th.U. utilised, per sq. ft. of heating surface per hour, or in certain cases, e.g., billet heating furnaces, it may be based merely on the hearth area. The implied classification must be such that, the furnaces are comparable as regards class of operation, e.g., forging, annealing, heat treatment, processing, etc., and size and class of material, thus, ingots large or small, castings heavy or light, etc., raw or finished material. Unless the load-efficiency characteristic of the furnace has been obtained for its range of working loads, the performance of the furnace has not been defined. The furnace is anologous to any other machine in this respect. By the " load-efficiency characteristic " is meant the relation given by the ratio of the thermal efficiency (or in many branches of metallurgical

practice, the fuel consumption per ton of material heated is equally significant) to the tonnage per furnace charge, or in the case of continuous furnaces, the rate of output. (See Fig. 6.) This may appear to be quite obvious, but it is surprising how many performances have been reported in which reference to the nominal capacity of the furnace has been entirely ignored, and so grave doubt left as to the true causes of any improvement found in comparison with other types.

GENERATION OF HEAT—RELATIVE SUITABILITY OF SOLID, LIQUID AND GASEOUS FUELS.

As to the relative efficiencies of various fuels in furnace practice, they may, undoubtedly, be put in the order of merit, (i.) gaseous, (ii.) liquid, (iii.) solid. Gaseous fuels are capable of thorough admixture with the supporter of combustion, air; are readily controllable as to the oxidising, or, so-called, " reducing " character of the furnace atmosphere, and, as to the critical feature of furnace operation, the rate of heat input. Regenerative principles, of returning the sensible heat of the waste gases, which must of necessity be high, in many metallurgical operations, back into the furnace in the combustible and the air, are most readily applicable.

Liquid fuel, to a lesser degree, has these advantages. In the case of oil fuel, perfect combustion is not so readily obtained under variable rates of combustion, unless with the more expensive and adjustable types of burner, and the intensity of the flame calls for special care in the heat distribution, and in the provision of superior refractory materials.

The disadvantages of solid fuel cover imperfect combustion conditions, ash troubles, and less flexibility of heat input. Every solid fuel bed is, in a sense, a gas producer, which, in the course of a few inches, has the same sequence of oxidation, reduction and distillation zones. It produces nearly 30 per cent. of volatile matter and, in the absence of channels, a complete utilisation of the oxygen, but it cannot be said that this form of firing has yet reached its optimum development. For the bulk of intermittent metallurgical heating furnaces, no successful means of maintaining such a small even fuel bed mechanically, has yet been found. But we venture to suggest that had as much attention and ingenuity been devoted to this branch of technology, with which we include the small gas-fired unit, as regards this statement, as there has been lavished, say, on pulverised fuel firing, there would now be in existence a mechanism, contributing very substantially, in this direction, to the economy of fuel in the metallurgical industry. Such a means of furnace firing, combined with adequate recovery of the sensible heat in the waste gases into the air used for combustion, would give the maximum utilisation of heat energy in the furnace, from those coals which are not suitable for preliminary treatment, such as carbonisation. The main difficulties to be overcome are economic, the provision of the necessary mechanical gear to feed the fire and discharge the ash, at a cost in keeping with the capital charges, which such a small unit can bear. Some preheating of primary air is necessary, for it is our experience that, in the existing so-called semi-producer fired furnace, the proportion of secondary air is not high, the ratio of primary to secondary air running on tests carried out on existing furnaces never becoming less than one, and approaching, frequently, an average of 9 to 1. Immediately after firing as much as 50 per cent. of the air used may be of secondary origin, depending on the manner of supply. But as the volatiles burn off, the amount of secondary air, actually utilised falls off asymptotically, to such a low value that the average percentage of secondary air used is only about 10 per cent. of the total.

Accordingly, preheating of secondary air on existing types of solid fuel fired furnaces may be undertaken with disappointing results. Preheating of primary air brings in clinkering troubles, but these are not serious with moderate preheat, and, in any case, the design of the grate and the provision of metals to withstand the more severe conditions are not insuperable, if a type of mechanical grate, capable of breaking up and removing the clinker be provided. As regards materials, metallurgical research has evolved heat-resisting steels, which are practically non-scaling at 1,000° C.,[1] and have a high creep stress limit above a red heat.

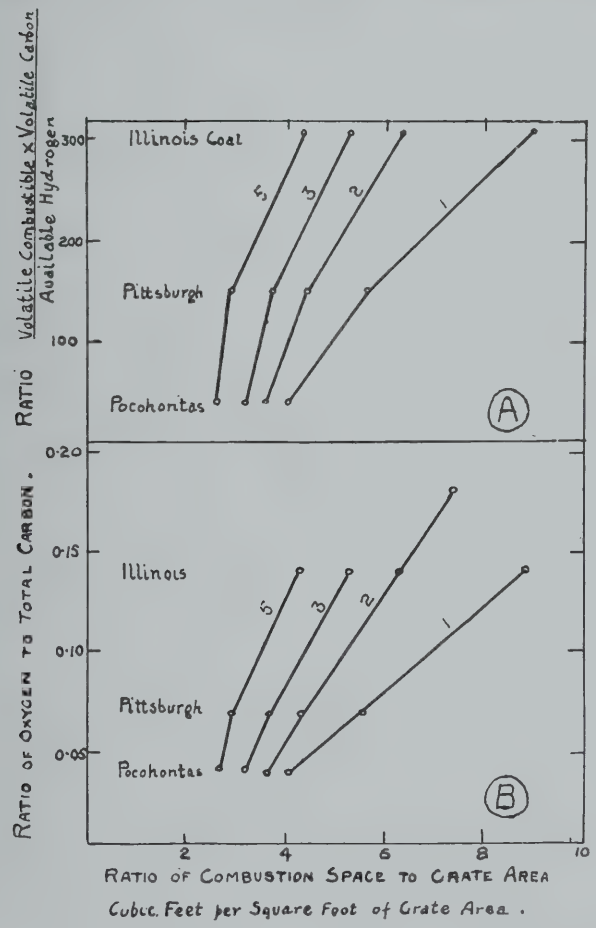
COMBUSTION—PORT AND BURNER DESIGN.

Flame Intensity. The characters of flame are governed by a complexity of factors, not yet completely elucidated. To gather for the present purpose, sufficient definition of a very wide subject, the temperature of the flame is highly important, as it decides the temperature gradient from the heating fluid,

the products of combustion, to the material heated. The "theoretical flame temperature," sometimes referred to as the "intensity of combustion," is that temperature which would be obtained, if the combustion took place instantaneously, and all the heat of combustion conveyed to the products of combustion. Alternatively, it is the ratio

$$\frac{\text{Potential Heat of Combustion} + \text{Sensible Heat in the Combustible and Air}}{\text{Heat Capacity of the Products.}}$$

It is high for the richer fuels, in the following order, water gas, oil, coal gas, coke oven gas, and low for producer gas and blast furnace gas. The intensities for solid fuel are dependent upon the character of the gasification process. It is, naturally, increased by the temperature of preheat of fuel or air, and, progressively,



$$\text{Influence of } \begin{cases} \text{A} & \text{Volatile Matter} \times \dfrac{\text{Volatile Carbon}}{\text{Available Hydrogen}} \\ \text{B} & \dfrac{\text{Oxygen}}{\text{Total Carbon}} \end{cases}$$

(Figures written against curves indicate percentage of undeveloped heat due to incomplete combustion. In tests, rate of combustion 50 lbs. and excess air 50%. U.S. Bureau of Mines Tests.)

FIG. 1.—*Combustion Space and Character of Fuel.*

reduced by increasing amounts of excess air. It is further governed by the manner of the combustion process. Thus, to get the maximum possible intensity, there must be perfect mixing and the liberation of heat, hastened by catalysts (surface combustion). To get the soft and lazy flame, beloved of the furnaceman in certain types of heat treatment, in which excessive flame temperatures are harmful, the mixing of combustible and air must be delayed by the port design.

The thermal efficiency of the combustion process, excluding losses due to unburnt combustible and changes of heat capacity of the gases with temperature, is given by the relation $\frac{T_1-T_2}{T_1}$ where T_1= the flame intensity as above defined; T_2=the temperature of the outgoing gases. The difference, T_1-T_2, represents the amount of heat used up and T_1 is a measure of the heat input.

Radiation from Flame. The difference between the theoretical and true flame temperatures is the loss of heat by conduction and radiation from the flame. In regard to this last, our state of knowledge is

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still incomplete. From the furnace standpoint, it is the most useful form of energy emitted by the flame. It is a function of the aeration of the flame and the composition of the gas. The radiating capacities of carbonaceous flames is, some 2.4 times that of hydrogen flames, expressed on the basis of the carbon dioxide and steam produced. Radiation drops off as the amount of primary air is increased beyond that necessary for complete combustion, and with any deficiency of air. The emission increases with increasing depth of flame, following an exponential law, up to a maximum thickness of 40 inches. It is greater with luminous flames. Lent and Thomas[2] added benzol to a blast furnace gas flame, making the flame strongly luminous, but regulated conditions, so as not to increase the flame temperature. The result was that the radiation was increased four-fold, and practically the same as from a black body at that temperature. As regards the effect of regeneration in high-temperature furnaces, from the theoretical and true flame temperatures found in open hearth furnaces, it has been deduced that the radiation approaches a value of the order of 25 per cent. of the potential heat of the gas.[3]

The above physical characters of the flame can only be put to effective use, if the heat radiated, from the walls of the combustion space, can be thrown into the heating chamber of the furnace. A convenient means is to arrange the arc of the arch, so that it can be "seen" as much as possible by the material to be heated. The lagging of the combustion chamber, up to the full practical limit, without undue loss of life of the refractories, is another noteworthy factor, and it should be a further practice to use the highest quality of refractories for this purpose, at least, a so-called first quality firebrick of moderately dense structure and high refractoriness under load.

Burner or Port Mixing the Prime Factor. The prime factor in the generation of flame, is the method of mixing combustible and air, and, from the standpoint of design, is largely a question of the application of the laws of the flow of gases. The hydraulic formula for fluid flow through an orifice, is applicable, within reasonable limits of error, with the added proviso that, due to combustion and increase of the volume of the gases, the principle of buoyancy operates and the flame is directed upwards according to the effect of the component force in that direction. A convenient form of the expression for the impelled stream at the orifice is $Q=166\ K.A.\ \sqrt{\frac{H}{d}}$. Where Q=discharge at the orifice in cu. ft. per hr.; K=discharge coefficient (0.60—0.90)* according to the angle of approach; A=area of the orifice (sq. in.); H=orifice pressure in inches water gauge; d=density of the gas relative to air.

The air or gas entrainment, is governed by the momentum (mass×velocity) of the impelling stream. The ratio between the momentum of this stream, and that of the stream of mixed gases, is the same for a burner of given design, irrespective of the pressure at the orifice, the density of the gas, or the volume delivered by the burner. Where the streams are large, as in the open hearth furnace, the results obtained by compounding the momenta according to the parallelogram law, do not accord entirely with practical observations. Thus, a small alteration to the slope of the air port has a more far-reaching effect, than would be indicated by the resultant obtained by calculation, even inclusive of the factor of buoyancy (see p. 14 et seq.).

A successful expedient, designed to control the flow of gases, which are not readily controlled by means of valves, owing to the choking effect of the dust and tar contained, e.g., raw producer gas, is to obtain the impeller effect by means of an auxiliary jet of high-pressure air. The proportion of air used is, only, of the order of 10 per cent. of the total requirement for combustion. In forced draught systems of this type, as in the case of the electrically-driven fan, it becomes possible to incorporate automatic combustion controls, at present, in the infancy of their development.

A further important means of governing the combustion conditions by the burner design, applicable only to gaseous systems of firing, is to inject a primary mixture of the gas and air, in such controlled ratio as to be insufficient for complete combustion, and at such a speed in the supply mains, as to exceed the velocity of backward propagation of flame. This is done, either by high-pressure injectors or fan mixers. In the case of surface combustion devices, the air-gas ratio is sufficient for complete combustion. In either case one injector, or fan, may supply fuel to a series of burner ports, and so permit even distribution of temperature, by localisation of a number of small flames.

*Small sharp edged orifices K = 0.61. Channel type, ·89.

Oil burners.

Gravity feed, mechanical atomisation and low-pressure air supply are generally the most economical means of adapting oil fuel for metallurgical heating furnaces, though special cases may favour other methods.

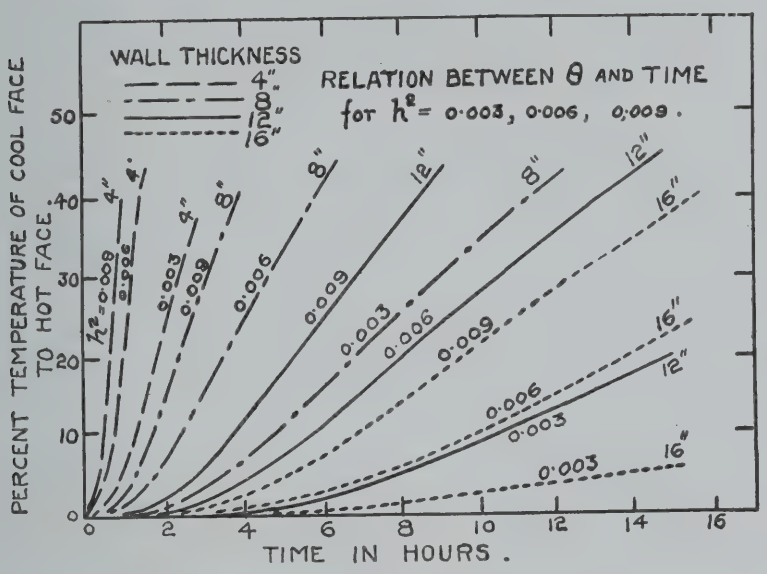

FIG. 2.—*Heat Distribution in Protected Walls.*

The flexibility of the method is confined largely to the intermittency of the operation, and not to the retention of maximum efficiency of individual burner operation, over a wide range of rates of combustion. A high combustion chamber temperature is required to sustain combustion, as well as an adequate provision of such space to obviate chilling of the gases, before combustion is complete.

The economic situation of this country in regard to the supply of oil fuel is such that, oil has only justified its extended use in mass production work, requiring high heating intensities in, relatively, small furnaces. The semi-muffle type, with the burner placed below the hearth is, accordingly, a convenient type. Preheating of secondary air should be the direction in which progress should be made. This has been facilitated to some extent by injecting the oil and the air at opposite points into a combustion chamber of highly refractory material, a carborundum, or sillimanite arch serving to form the outlet flue system, leading the highly heated products of combustion to the working chamber.

Solid fuel firing.

Before passing on to indicate the combustion space that must be allowed for each type of fuel, it is necessary to touch, briefly, on the factors which determine the length of the flame in solid fuel furnaces. For detailed exposition, reference should be made to the report of an investigation, by the American Bureau of Mines.[4] The experiments were run in a furnace giving rapid mixing of the combustible gases and the secondary air, which was supplied over the fuel bed, for a combustion rate ranging from 20-120 lbs., per sq. ft. of grate area, per hr.

For Pittsburgh coal, resembling a good class furnace coal in this country (13,365 B.Th.U./lb.), and a higher oxygen coal (Illinois) of only 10,433 B.Th.U./lb. heating value, the following data was obtained regarding (i.) Effect of excess air (Table I.), (ii.) rate of combustion (Table II.).

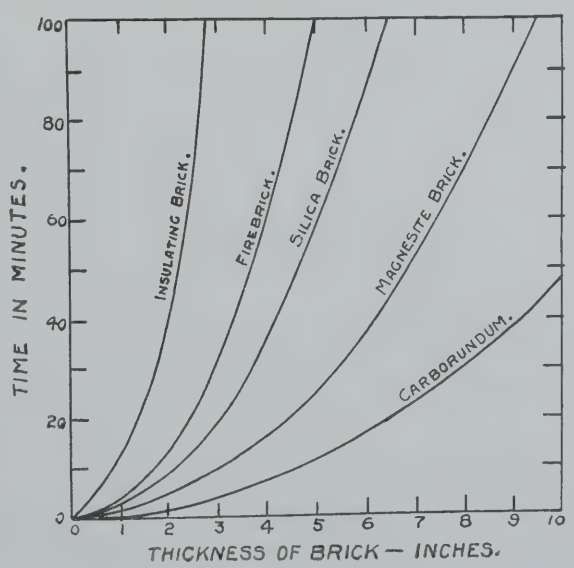

FIG. 3.—*Thickness of Brickwork to give 95% Saturation in various intervals of time.*

Character of the fuel.

Beyond the operation of other physical factors, the rate of heating the coal, the shape of the combustion space, involving the length of travel of the gases and the temperature of the combustion space,

there was found a definite relation between the volume of the combustion space requisite, and certain characteristics of the coal indicated in Fig. 1.

TABLE I.—COMBUSTION SPACE AND EXCESS AIR.

Ratio of Volume, cu. ft. to grate area, sq. ft.			
Coal.		Pittsburgh. Run of Mine.	Illinois.
Combustion Rate, lbs./sq. ft. grate area/hr.		20	20
% Undeveloped Heat, at tip of flame		1	2
% Excess Air :	75	3.3	3.8
	50	3.7	4.9
	35	4.7	...
	25	7.8	6.8
	10	...	8.5

TABLE II.—COMBUSTION SPACE AND RATE OF COMBUSTION.

Ratio of Volume, cu. ft. to grate area, sq. ft.			
Coal.		Pittsburgh. Run of Mine.	Illinois.
% Excess Air in Flame		15	10
% Unburnt Combustible at tip of flame		3	3
Rate of Combustion lbs./sq. ft., grate area/hr.:	20	7.6	7.5
	40	8.3	11.0
	60	10.8	14.2

It has not yet been ascertained whether these relations hold for British coals. During recent years, much attention has been devoted, in this country, to the study of the banding constituents of the latter, which differ in marked degree as regards their caking, tar forming and other properties. Breakdown of the coal lumps, caking, the condition of the coke, and clinkering properties of the ash formed, must influence the distribution of the air supply through the fuel bed, and so govern the combustion space necessary. Accordingly, it cannot be concluded, as a general rule, that the burning properties are solely a function of the chemical character of the fuel and its size. Again, the manner of supply of secondary air, as in the case of liquid and gaseous fuels is a dominant factor.

Basis for determining combustion space.

In the tests cited, the average development of heat per unit volume of combustion space, ranged from 15 to 32 B.Th.U., per cu. ft., per sec., but, actually, the rate of heat evolution over the travel of the burning gases is wide, giving a hyperbolic relation, varying from over 10 B.Th.U. to under 2 B.Th.U. per cubic ft., per sec., for a change of a few units in the ratio of the volume of combustion to grate area, for rates, say of 25 lbs. per sq. ft., per hour, on the grate and 75 per cent. excess air, on Pittsburgh coal.

For furnaces running on the same type of fuel, the rate of heat evolution, per unit volume, should be the basis of comparison. In powdered coal firing, the best results are obtained with a range from 3 to 4 B.Th.U., per cu. ft., per second, but good results may be obtained with a range from $1\frac{1}{2}$ to 6. These values are near the order of provision of combustion space in many metallurgical furnaces, though a value of 15 B.Th.U., per cubic foot, is attained with good flame mixing in regenerative and recuperative practice. Following the influence of Siemens, the tendency has been to err on the side of over-estimation

of the combustion space requisite for economical working, though such provision must readily be admitted, where even heating demands that the flame be kept well off the stock. Much higher intensities are obtained with surface combustion, amounting to figures as high as 70-190 B.Th.U./cu. ft./sec. Conjointly, with rates of heat evolution of the orders indicated, the velocity of the hot gases should be kept below a critical limit of about 30-40 ft./sec., except in melting furnaces, in which the maximum attainable velocity is an advantage.

TRANSFER OF HEAT TO THE CHARGE.

The three well-known agencies—conduction, radiation and convection—must be studied separately though all operate simultaneously. To illustrate some concrete cases in a continuous billet-heating furnace, the first transfer of heat to the cold billet is by the scrubbing of the gases against the surface of the charge, at, relatively, low temperatures and the rate of heating is a function of convection transfer from the hot

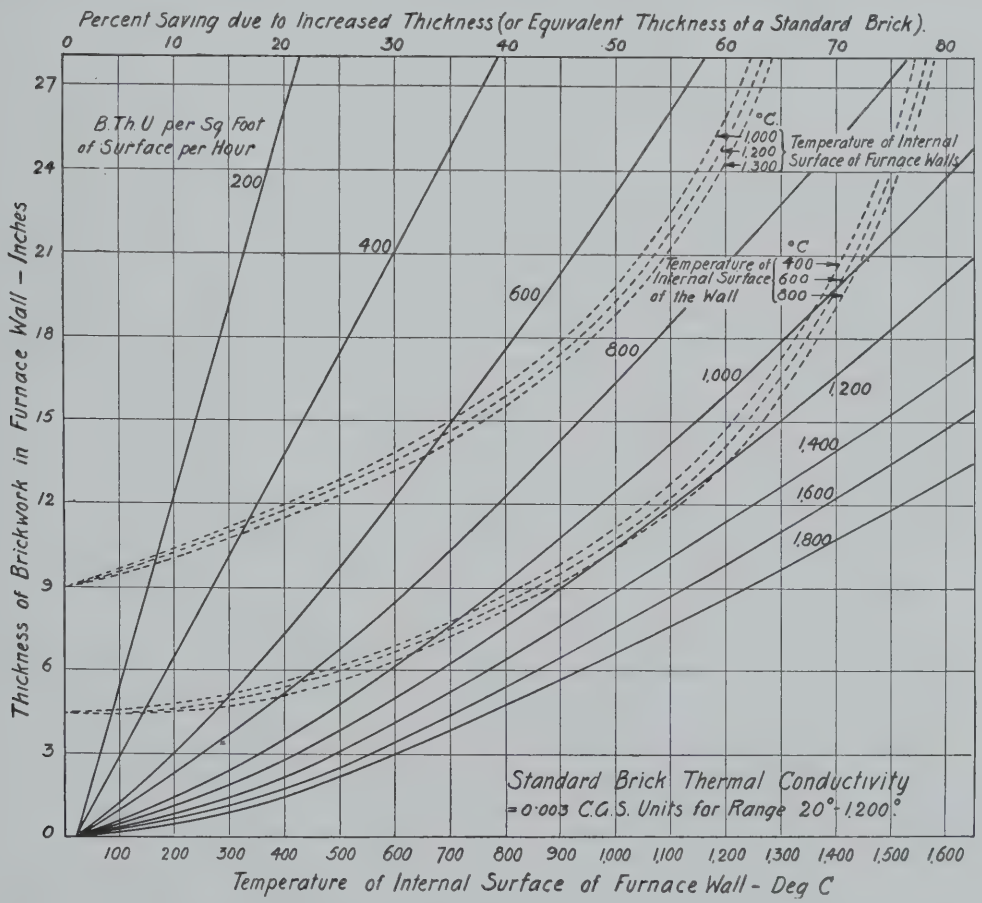

FIG. 4.—*The Influence of Added Thicknesses of Insulation upon Heat Loss from Firebrick Wall (Steady State).*

gaseous stream and the conduction into the mass of the billet. Radiation is less effective at low temperatures. As the billet passes to the hotter regions of the furnace, heat is transferred more effectively by radiation from the hot walls, but, again, for larger sizes of billets, say over 4 inches in diameter, or width, the heating rate is mainly governed by the heat conductivity of the material.

In certain types of furnace, special provision is made to embody particularly one or other of these modes of heat transfer. Thus, in the rotary flame type of furnace there are combined the advantages of high velocity of flow, a long distance of travel of the gaseous heating stream and turbulence arising from

the eddying associated with fluid motion beyond the critical velocity, under 1 foot, per sec., for most conditions met with in practice. It is taken for granted in this exposition, that the rationale of the various laws of heat transfer are understood, reference being made to other chapters of this book for their special study, and it, therefore, only remains to indicate their bearing in the special problems of furnace design.

Radiation from hot surfaces.

In the application of the Stefan-Boltzmann law, expressed as follows:—$H=E(T_1^4-T_2^4)$; where H =radiant energy exchanged; E=emissivity of the radiating surface; T_1=absolute temperature of the hot surface ; T_2=absolute temperature of the cold surface ; the emissivity coefficient for black body conditions is, $E=7.65\times10^{-11}$(C.G.S. units: cals. per sq. cm., per min.) or 2.66×10^{-11}(English units; B.Th.U. per sq. ft. per min.). In practice, the radiation is frequently less than black body, and then a mutual coefficient

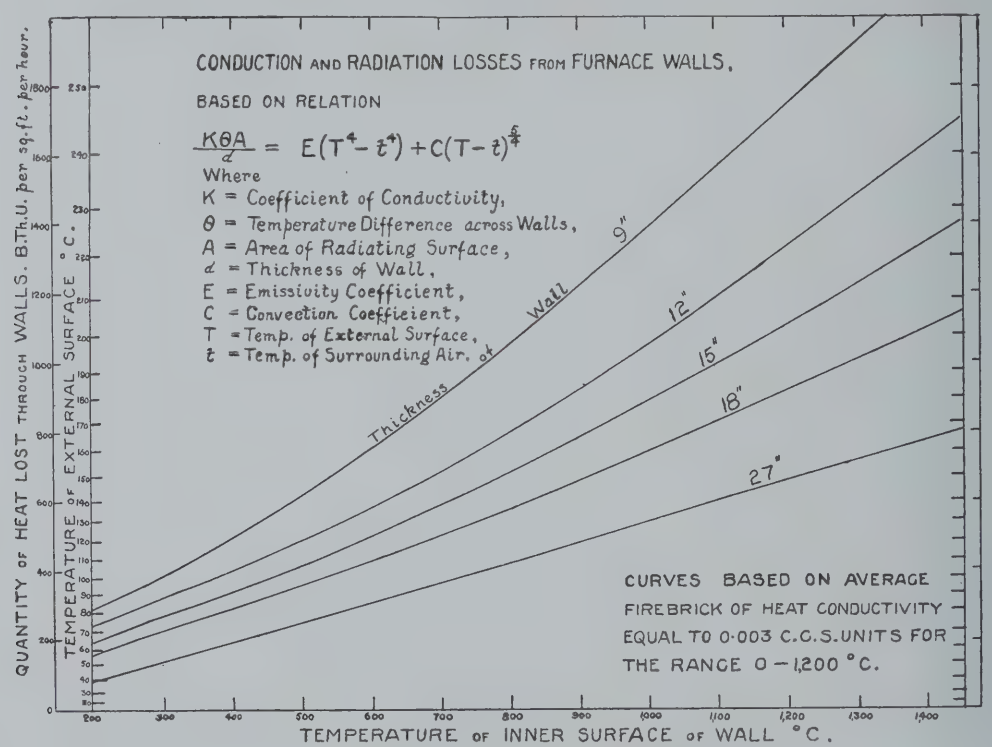
CONDUCTION AND RADIATION LOSSES FROM FURNACE WALLS,
BASED ON RELATION
$\frac{K\theta A}{d} = E(T^4 - t^4) + C(T-t)^{\frac{5}{4}}$
Where
K = Coefficient of Conductivity,
θ = Temperature Difference across Walls,
A = Area of Radiating Surface,
d = Thickness of Wall,
E = Emissivity Coefficient,
C = Convection Coefficient,
T = Temp. of External Surface,
t = Temp. of Surrounding Air.
Thickness of Wall
9"
12"
15"
18"
27"
CURVES BASED ON AVERAGE FIREBRICK OF HEAT CONDUCTIVITY EQUAL TO 0·003 C.G.S. UNITS FOR THE RANGE 0 – 1,200 °C.
QUANTITY OF HEAT LOST THROUGH WALLS. B.Th.U. per sq. ft. per hour.
TEMPERATURE OF EXTERNAL SURFACE °C.
TEMPERATURE OF INNER SURFACE OF WALL °C.

FIG. 5.—*Heat Losses from Furnace Walls.*

becomes necessary expressed as follows: $e=\dfrac{1}{\frac{1}{e_1}+\frac{1}{e_2}-\frac{1}{E}}$, Where e_1, e_2 represent values of the coefficients for the exchanging surfaces. For general use in furnace problems, *e* becomes 0.90 to 0.93 of the black body value. A further point of importance is the extent of the hot surfaces and the solid angle of exposure to the cold surfaces of the furnace. An interpretation of the radiation law may be cited as follows.—Assuming the furnace coefficient to be 0.90, the hot surface 1,100° C., and the cold body, 300° C., and the solid angle such that 50 per cent. of the total radiation is received by the cold surface, then the transmission of heat, per sq. ft. of hot surface, is 3.74 B.Th.U., per second. If the temperature of the hot surface be raised to 1,650° C., the transmission becomes 14.2 B.Th.U., per second, or nearly four times as much.

Upon the influence of radiation depends the even character of the temperature of the charge of an intermittent furnace, when " soaked," that is to say, when the furnace is damped down and just sufficient heat applied to make good the " losses."

Convection.

The rates of radiation are so high above 800° C., that what virtually determines the effectiveness of the brickwork, is the rate at which heat may be transferred thereto by the hot gases, and this is, apart from the energy directly radiated by the flame, a function of the convection transfer. To summarise the results of a long series of classical researches, associated with the names of Reynolds, Stanton, Nicolson, Jordan, Nusselt and others, the following are the governing features:—

(i.) For a constant weight of gaseous flow, the heat transmission is proportional to the difference in temperature of the hot gas and the heated surface.

(ii.) For a constant temperature difference, it increases with the mass velocity of the gases, within limits, according to a linear law.

(iii.) For a given flow and temperature difference, the heat transfer increases with the value of the temperature.

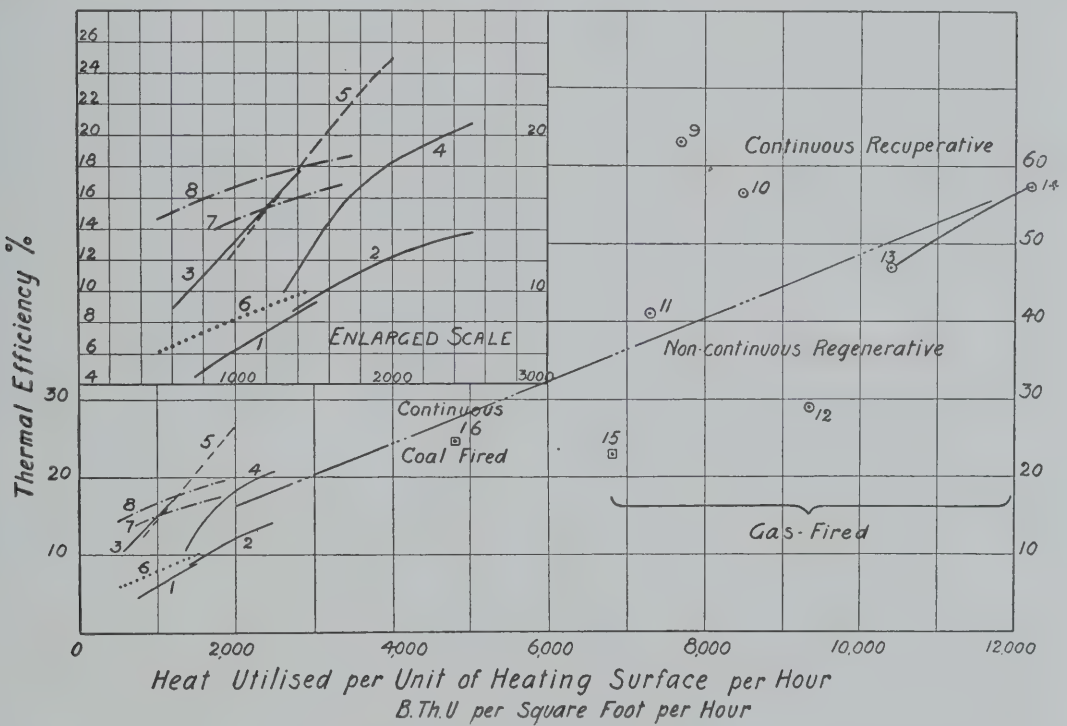

FIG. 6.—*Relation between Thermal Efficiency and Heat Utilised (B.Th.U.) per sq. ft. of Heating Surface per hour.*

Curve No.:—(1) and (2) Forge Furnaces, coal fired, billets 60-80 lbs. (3) Forge furnaces, coal fired, billets 100-250 lbs. with some heat recovery. (4) Reheating furnaces, regenerative producer gas fired. (5) Reheating furnaces, open flame gas fired. (6) Muffle furnaces, gas fired. (7) Heating furnaces, regenerative producer gas fired, intermittent, temp. 1,000° C. (8) Heating furnaces, regenerative producer gas fired, intermittent, temp. 800-850° C.

Points (9)—(14) Recuperative and regenerative gas-fired (Table VIII.), see Chandler, Amer. Iron and Steel Inst., 1922. (15) Recuperative, continuous, producer gas fired, ingot heating (Table IX.). (16) Coal-fired continuous billet heating (Table IX.).

(iv.) It is a function of geometrical relations, thus, as worked out in tubes, upon the ratio of the area to the perimeter, the heat transfer increasing with diminished depth.

(v.) The condition of the surface is a contributory factor, the rougher the surface, the better the heat transmission.

The most applicable means of evaluating convection transfer, is based on the fundamental conception of Reynolds that the heat interchange between a solid surface and a fluid in contact with it, depends upon, (i.) a molecular diffusion in the mass of fluid at rest, constituting what is known as the thermal conductivity as expressed by Newton's law; (ii.) diffusion by means of the movements of small portions of the fluid in the form of eddies, due to the mechanism of convection.

Stanton[5] has further extended Reynold's work and shown that, whilst without further investigation no reliable prediction of the amount of heat transmission can be made from a knowledge of the frictional

resistances of the fluid and surface, there was a definite field for research in increasing heat transmission by making use of such relationships. Thus, in experiments made at the National Physical Laboratory, a $1\frac{1}{8}$ in. pipe, roughened with a screw cutting tool, transmitted $2\frac{1}{2}$ times as much heat as a smooth pipe.

The conception of a stationary film in contact with the solid body has been shown to exist experimentally by Langmuir[7], who found that at a point, approximately, 0.1in. from the edge of heated silver plate, the temperature began to rise rapidly, until it reached the temperature obtained by touching the plate with the measuring thermo-couple. The value of the " film coefficient " is, generally, the most important of any in heat transfer problems. The subject is dealt with again on p. 270 in connection with recuperators, and losses from furnace walls.

Inside the furnace, it is a more difficult matter to ascertain its value separately and, accordingly, it is more convenient to combine it with the coefficient for heating by radiation, by transferring the radiation equation into one of the same type as the convection equation, thus:—$H=\frac{Q}{\theta}=e.\ A\ (T_1^4-T_2^4)=e\ A\ (T_1-T_2)\ (T_1^3+T_1^2\ T_2+T_1\ T_2^2+T_2^3)=h_r\ A\ (T_1-T_2)$, where h_r is the coefficient, including the emissivity correction and the term $(T_1^3+T_1^2\ T_2+T_1\ T_2^2+T_2^3)$, and so varying with the temperature of the wall and the charge ; Q=total energy radiated (B.Th.U.); θ=time (hours); A=area (sq. ft.).

Haslam and Russell[8] quote values of h_r based on experiments carried out at the Massachusetts Institute of Technology, varying in the range 4-50 B.Th.U., per sq. ft., per hour, per °F. for furnace temperatures in the range 1,000°-2,200° F. (538°-1,204° C.) and charge temperatures, up to 2,000° F. (1,093° C.). The " forced convection " coefficient, which may now be combined directly with the above (i.e., h_r+h_c), is most conveniently obtained from Weber's equation as follows:—

$$h_c=\frac{0.88\ (V^{0.8})\ (T^{0.5})\ (S^{0.2})\ C_p.;}{M^{0.3}}$$

where h_c=coefficient in B.Th.U./hr./sq. ft./°F., V=mass velocity of the gas (lbs./sec./sq. ft.), T=temp. of gas (°F absolute). S=surface factor, the mean hydraulic depth, or area of surface (sq. ft.), divided by the volume of space through which the gas is flowing (cu. ft.) C_p=average specific heat of the gas at constant pressure; M=average molecular weight of the gas.

This equation was based on a consideration of all available data, which is confined, however, to gas velocities under 20 lbs. per sq. ft. of free air, per second, small pipes and a temperature range up to 1,100° C. In many commercial operations the convection coefficient runs between 2 and 6 B.Th.U. per sq. ft. per hour per °F. (27.1 to 81.4 by 10^{-5} cals. per sq. cm./sec./°C.). There is need for further exploration of the problem to meet the more special needs of metallurgical heating furnaces.

Trinks[9] gives an expression in the form :—$H=A\ (K'+qK''c.)\ (T_1-T_2)$, H=heat transmission in B.Th.U. per hour. A=area (sq. ft.). K′=coefficient of diffusion (1.5 to 2.5). K″=coefficient of turbulence (2.25 to 4.25). q=density of the gas (1lb. per cu. ft.). c=velocity of hot gas (ft. per sec.). T_1 and T_2 = temperatures (°F.) of the hot gas and heat absorbing mass, respectively.

Heat conduction into the charge.

A rigorous solution of a new furnace problem by methods of calculation from the known laws and coefficients of heat transmission, is not only tedious and difficult, but, in the present state of knowledge, possibly inaccurate. However, a reasonable combination of such methods, with data obtained from existing furnaces of similar type, constitutes a valuable aid towards sound scientific design. By derivations from the fundamental equation of Fourier, on which now a hundred years of mathematical ingenuity has been expended, much theoretical assistance may be obtained, in problems of heat conduction through solids. Thus, it may be shown that in any case of heating, covering that of a semi-infinite solid, with one plane at a constant temperature, the rate of heat penetration is such, that any particular temperature is attained at distances x_1 and x_2 from the boundary in times t_1 and t_2 according to the relation

$$\frac{x_1}{2h}\sqrt{t_1}=\frac{x_2}{2h}\sqrt{t_2}\ \text{ or }\ \frac{t_1}{t_2}=\frac{x_1^2}{x_2^2}$$

The term h^2 used in conduction equations is an expression for the diffusivity of the substance, defined as follows :—

$$\text{diffusivity } (h^2) = \frac{\text{thermal conductivity (K)}}{\text{specific heat (c) x density } (\rho)}$$

The above conclusion is important, is known as the " law of times," and means, in plain language, " that the times which it takes a given temperature to penetrate the solid, under the conditions specified, is proportional to the square of the distance."

One illustration will be given of the application of these methods to problems in furnace technology. The conditions for the use of the expression are that one face of a wall be suddenly raised to a temperature θ_o, and maintained at that temperature whilst the rear face is protected from loss of heat. When the surface temperature of the wall of the solid (it may be of the charge, if its conditions meet those specified) is rising slowly, which applies actually in practice, an approximate value of θ_o may be taken as the mean of the rise, or an added thickness may be imagined, suddenly raised to and kept at a constant temperature.

Then using the expression

$$\theta=\theta_o \left[1- \frac{4}{\pi}.e^{\frac{-h^2\pi^2 t}{l^2}} + \frac{4}{3\pi}.e^{\frac{-9h^2\pi^2 t}{l^2}} - \frac{4}{5\pi}.e^{\frac{-25h^2\pi^2 t}{l^2}} + \ldots\ldots \right]$$

where θ=temperature of the point considered at time t. θ_o=temperature at surface. l=twice the distance between the points at temperatures θ and θ_o, respectively, a measure is obtained of the rate of heat penetration.

Thus is obtained the data illustrated in Fig. 2, and the curves due to Hougen and Edwards[10] shown in Fig. 3, alluding to the times of heating necessary to produce 95 per cent. temperature saturation in various types of refractories. So is derived the useful conclusions, that with regenerator bricks of 3in. thickness of firebrick, reversals should be made every half hour, with silica brick a $2\frac{1}{2}$in. chequer brick requires reversals every 15 minutes, and a 3in., every 20 minutes.

For relationships worked out for slabs, cylinders and spheres the reader is referred to an interesting study by H. P. Gurney and J. Lurie[11], in which the rate of heat penetration, relative to the pertinent factors, is worked out, involving the value of the combined heat transfer coefficient (h_r+h_c) noted above.

An interesting comparison has been noted by the author[12] between the times actually taken for soaking large ingots, and the time for heat penetration into spherical masses of the same tonnage (the equivalent sphere), as calculated from the Fourier equation—Table III.

TABLE III.—SOAKING TIMES FOR SPHERICAL MASSES OF STEEL.

(Time in Minutes.)

Wt. of Mass. cwt.	Diam. ins.	For 95% Saturation.		For 99% Saturation.		Actual[13] practical requirements for normal mild steel ingots.
		Mild Steel. h^2=0.173.	Hard Steel. h^2=0.121.	Mild Steel.	Hard Steel.	
20	21.2	18.6	26.6	30	43	30
35	27.6	31.7	45.3	51	73	45
45	32.2	43.0	61.4	69	99	60

Heat losses through furnace walls.

The furnace wall has a two-fold function (i.) refractoriness, mechanical resistance to flame temperature, and the slagging action of the furnace fume, and (ii.) heat insulation. It is not possible to secure

the ideal combination of these properties in one material. Accordingly, the former must be sought in the best quality firebrick or silica brick, the latter in special materials, whose essential feature is a high proportion of pore space, obtained in the siliceous skeletons of the minute marine animals constituting the substance of the material frequently used, namely, diatomaceous earth. The effectiveness of such lagging depends upon the minuteness, multitude and even distribution of cells of air, the heat conductivity of which is extremely low.

In order to determine the ideal thickness, the total loss by conduction must be obtained by the usual method of computing the total thermal resistance of the wall for various thicknesses, determining the value of the net saving of heat, and its economic value in relation to the working life of the brick and the furnace. On plotting the values against the thickness, the economic thickness is readily obtained. Fig. 4 indicates the percentage of heat saved by additional thickness, beyond standard 4½in. and 9in. thicknesses. The equivalent thickness of insulating brick may be substituted by taking each 4½in. of firebrick, as equivalent to 1in. or ½in. of insulating brick, according to the value of the heat conductivity of the latter.

Heat storage in brickwork.

The loss of heat is made up of two types, that lost by storage in the brickwork, and that lost by radiation and convection from the outer surface. It will be readily appreciated that, whilst with certain types of in and out furnaces, small forge furnaces, a portion of this storage is recovered in heating cold stock, in the large intermittent furnaces there must of necessity be a large loss, especially when, as in certain heat treatment operations, the charge is cooled in the furnace. The estimation of this is a simple matter, if the measure of the heat penetration in the wall is known. The solution of the latter is complex and requires the application of the Fourier series. Fig. 2 is derived in such a manner, which may be interpreted by reference to Table IV. below :—

TABLE IV.—HEAT CONDUCTIVITY AND DIFFUSIVITY (h^2) OF REFRACTORY MATERIALS.
(15—1,200° C.)

Material.	Apparent Density	Specific Heat.	Conductivity.	Diffusivity.
			c.g.s. units. x 10—^{3}.	
Firebrick	1.9—2.0	0.25	2—3	4—6
Silica brick	1.55—1.65	.25	2—4	5—9
Magnesite	2.2—2.6	.26	5—9	7.5—14
Sand	1.4	.25	1.5—2.5	4—7
Insulating brick	0.5—0.8	.20	0.2—0.5	0.2—0.5
Carborundum	2.1—2.5	.26	10—27	20—50
Air	0.00129	.25	0.05	0.179

Computing the radiation and convection loss.

In regard to the heat loss from the external wall, which is made up of the radiation and convection loss, the former follows the usual law, and the latter is governed by the atmospheric conditions prevailing and the geometrical shape of the surfaces.[14]

The direct measurement of the actual heat loss from furnace walls, is an operation fraught with possibilities of error due to the uncertain influence of draughts. However, the chart presented in Fig. 5, reproduced from a conjoint paper of Sir Robert Hadfield and the author, first published in 1919, indicates a convenient means of combining the radiation, convection and conduction laws and equating the heat

conducted through the wall, to the heat lost from the wall. The emissivity factor may be determined from the table following :—

TABLE V.—EMISSIVITIES OF SURFACES RELATIVE TO BLACK BODY CONDITIONS.

Lampblack	0.95—0.98
Highly oxidised iron	0.91—0.85
Iron oxide scale	0.85—0.89 (500—1,200° C.)
Brick	0.78
Wrought iron	0.60
Rusty cast iron	0.56—0.53 (50—500° C.)
Highly polished metals	0.02—0.05

The convection loss, for still air convection, is of the order 4.5 to 4.85 by 10^{-5} cals. per sq. cm. per sec. on the basis of National Physical Laboratory tests for vertical walls. For convection upwards from horizontal walls increase by 10 per cent.; for convection downwards by 50 per cent. Shop draughts may increase this loss considerably.

THE FLOW OF GASES IN FURNACES.

Most of the exact work on the flow of gases has been concerned with the conditions existing with turbulent motion in a confined duct. In metallurgical furnaces there applies, however, the flow of gases, in a more or less free space, in which the natural buoyancy of the gas due to its change of density, with change of temperature, operates. The name of the Russian scientist, W. E. Groum-Grjimailo, is associated with a very lucid work on this subject.[15] It would be beyond the scope of this article to do more than briefly mention the chief features of a study, which if all of its findings cannot be accepted by furnace technologists, has had a far-reaching effect in directing attention to the operation of the laws of the flow of gases, in what may be termed an unconfined duct.

In 1738, Bernouilli showed that the law of conservation of energy is applicable to the flow of gases, that whatever energy is lost as pressure is gained as velocity, excluding the influence of friction, and mechanical work done on or by the gases, or total energy=pressure head+head due to position+velocity head.

The familiar chimney action of hot gases has for a basis the fact that the Archimedean pressure is exerted equally in all directions, and is related to the temperature by the gas law, that for every degree rise of temperature (°C.) the volume is increased by $\frac{1}{273}$ of its volume at 0° C. For the method of converting the buoyancy of a gas, in terms of its temperature rise, and, consequently, its change of density, into pressure head, some other work of reference must be consulted.[16]

Further, the well-known expression for interpreting the pressure head in terms of velocity, that, $v^2=2gh$ (p. 5), where v=velocity, h=pressure head, g=gravitational constant, is, virtually, the same as the principle enunciated by Torricelli in 1643, that the velocity of a fluid passing an orifice in the side of a reservoir, is the same as that acquired by a body falling freely *in vacuo* from a vertical height, measured from the surface of the fluid to the centre of the orifice. It is upon these bases, and due allowances for the operation of friction, referred to later, that expressions for the draughting of furnaces are built up.

Important practical derivations from the principle of the buoyancy of hot gases are the following:— (i.) It is impossible to obtain uniform heating of portions of a divided furnace where the flow of the gas is upward, for as the temperature of any section rises, more of the gas flows through that section since the energy available to produce flow becomes greater. (ii.) Gases that are being heated should rise. Cooling gases should be directed downwards.

For the purpose of obtaining guidance in the selection of the heights of crowns and other dimensions to ensure that the hot gases must " wash the hearth," Groum-Grjimailo put forward the inverted weir

formula of Yesmann, on the assumption that the flow of hot gas, under an arch, is represented inversely by the flow of water over a thick-crested weir.

The formula is:—$Q_t = B\sqrt[2]{\frac{h_t^3 - t}{A^3}}$, where Q_t=volume of flow in cubic feet at t °C.; h_t=depth of the current (feet); B=width of the flue (feet); A=constant dependent both on h_t and the length of the channel, E, in feet.

TABLE VI.—VALUES OF THE CONSTANT A IN YESMANN'S FORMULA.

			h_t (feet)
	1.	2.	3.
2.5	2.270	2.040	1.905
5.0	2.370	2.260	2.165
7.5	2.400	2.330	2.265
10.0	2.415	2.365	2.315
15.0	2.430	2.405	2.365
∝	2.555	2.485	2.465
E (feet)			

Thus, in a horizontal stream for a depth of gas stream of 1 foot, the velocity of the gases increases from 6.7ft. per sec., at 600° C., to 10.2ft. per sec. at 1,400° C., and, for a depth of 3 feet, 13.7 to 21.0ft., per sec., for the same temperature range. Other points arising from this study, to which agreement may be accorded, provided allowance be made for any influence of radiation heating, are:—

(i.) In order to equalize temperatures in a high furnace, the hot gases should ascend around the periphery, and descend along the axis.

(ii.) The space below the crown, is the ideal combustion chamber in a furnace.

(iii.) The hearth should, when possible, be provided with flues, to prevent the formation of pockets of cold gas.

(iv.) Ingot and billet furnaces of the continuous type, should be provided with sufficient depth below the skids to allow of flow of cooled gases to pass downwards between the ingots to the stack.

(v.) The pressure within a furnace, with doors or working openings, should approach zero, the pull of the chimney being sufficient only to exhaust the products of combustion through ports, regenerators and flues. In a word, balanced draught is desirable.

(vi.) Working doors and openings should be placed as low as possible, and at the same height.[17]

The draughting of metallurgical furnaces.

It remains to summarise, briefly, the data pertinent to the flow of gases through the ports and flues of the furnace system. Returning to Bernouilli's energy balance, there is the consideration of the effect of friction, and any possibility of work being done on, or by the gases, at changes of section of the path of flow. The draughting of a furnace is, usually, expressed in terms of inches of water gauge for the pressure head, and, thus, the most convenient form for stating the combined loss due to velocity and friction is as follows:—$\Delta h = 0.814\,\rho\,\frac{V^2}{T}\left(1 + f\frac{L.}{m}\right)$, where Δh=loss of pressure head in inches w.g.; ρ=density of gases at N.T.P. (lbs. per cubic foot); f=coefficient of friction;* V=velocity in feet per second; L=length of duct in feet; m=hydraulic radius of flue=$\frac{\text{area of cross section}}{\text{perimeter}}$; T=temperature absolute, °C.

This is a combination of the usual expression for velocity flow, with the Fanning equation. The value of the friction factor, has been found to vary with that of a modulus $\frac{D\ u\ s}{z}$[18], where D=diam. in inches of the flue (circular); u=velocity of gases, ft. per sec.; s=specific gravity of gases, relative to water; z=relative viscosity of gases at temperature in question referred to water at 68° F. (centipoises).

*For detail of coefficient consult reference 16.

That is to say, the friction coefficient itself varies with the temperature of the gases, upon which both the density and the viscosity depend. Again, there are losses of pressure head due to contractions of area of duct, since there is conversion from static pressure in the larger, to velocity in the narrower section, and vice versa for expansion, or $\Delta h_c = 0.186\ K\ u^2\ s$, Δh_c=pressure loss due to contraction of area of section, inches, w.g.; K=contraction loss coefficient, varying from 0.5 to nil as ratio of areas approaches 1^{19}; u=velocity of gases (ft./sec.) in smaller section; s=specific gravity of gases relative to water.

The published data on this subject is somewhat meagre, owing to the absence of any extensive experimental inquiries. In any case, in fixing flue dimensions, allowances have to be made for the inevitable choking with flue dusts. Minimum areas are, further, frequently fixed by questions of accessibility for cleaning and repair. A reasonable margin of safety is, naturally, to be preferred, reliance being placed on the damper for attaining the best balance of working.

HEAT RECOVERY.

A fundamental character of many metallurgical heating problems, is that the temperature of operation determines a minimum content of sensible heat in the products of combustion, which must pass out of the working chamber. For gases burnt without an appreciable excess of air, this loss is of the order 50-60 per cent. for an issuing temperature of 1,200° C., and 20-25 per cent. for 600° C. Among the practicable means of returning this waste heat to the furnace are, (i.) to preheat the material of the charge, various expedients being the continuous furnace, and the batch furnace in which the waste heat from one furnace passes into a cold charge in an adjoining one; (ii.) to preheat the air for combustion by either (a) recuperation, or (b) regeneration (heat exchange by reversible flow through chequered masses of brickwork).

The following table, which gives the proportion of heat in preheated air, expressed as a percentage of the gross potential heat in the fuel, indicates to what degree a proportion of the heat may be returned to the furnace in the form of sensible heat in the air for combustion.

TABLE VII.—HEAT RECOVERY BY AIR PREHEAT.

Temp. °C. of Preheat.	For a good Bituminous Coal of 14,200 B.Th.U. per lb. dry.	Producer Gas Saturation Temp. of Blast=55°C. Heating Value=168 B.Th.U. per cubic ft. gross.
200	5.6	4.4
400	11.7	9.17
600	18.1	14.16
800	24.8	19.32
1,000	31.6	24.62

It is apparent from these values, that if the proportion of secondary air, which is preheated does not exceed 20 per cent. of the total air supply, the extra cost of constructing and maintaining a recuperative system may not cover the value of the fuel saved. There is, however, a feature of great importance in regenerative and recuperative practice, namely, that the effective temperature gradient, from the heating to the heated medium, is increased to a greater degree than that corresponding to the mere recovery of heat from the waste gases. Thus, in the case of the heating of a furnace at 1,300° C., by means of producer gas, preheated to 500° C., the percentage increase of heat supplied to the furnace is 8.5 per cent. and 12.6 per cent. by preheating the air, to 400° and 600° C., respectively, assuming complete combustion. But the gain in "theoretical temperature gradient" (i.e., from theoretical flame temperature to a temperature of 1,300° C.—see p. 257) is, actually, increased from 37.6 to 50.7 per cent. by the same degree of air preheat.

Recuperators.

The rationale of the heat exchange in recuperators, follows the operation of laws already indicated. The heat transfer is dependent upon the heat conduction through the wall, and the adherent film of air on either side (pp. 261-264). An important point is the influence of velocity in increasing the value of the convection transfer. In refractory recuperators, it is not possible, generally, to make use of this aid to efficiency, since their fragility more readily induces leakages, but with metallic recuperators, forced draught can be used, producing high velocities and increased utility of the available surface. Also, thin walls and a lighter construction are possible. Such advances in recuperative practice are now applicable, by the use of the heat-resisting steels which are malleable, being capable of being rolled into bars and sheets, welded, bolted, etc., and thus built up as a comparatively light and robust structure.[20]

In suitable designs efficiencies usually run between 30-60 per cent., in terms of the percentage of heat returned to the furnace, of that leaving it in the sensible heat of the waste gases. The recuperator finds its best utility in gas-fired furnaces of continuous type. It is usually of three types—the parallel flow, counter flow, and cross flow types. The first is more often found in metallic recuperators, since the immediate contact of the hottest portion of the heating fluid with the coldest portion of the incoming air, tends to give the lowest maximum temperatures in the walls. The counter flow type, on the other hand, gives the highest temperature of preheat, and is preferable where refractory material of, relatively, low thermal conductivity is used, e.g., firebrick. The cross flow has the advantage, in that it permits the stream which has the less draught available to propel it to take the easier course, and follow the natural flow due to its buoyancy and to have the least frictional resistance.

Regenerators.

By way of outline of progress in a wide subject, the major principles in regenerator design are:—(i.) Regenerators should be arranged vertically, and have adequate depth for the furnace requirement. (ii.) The partition of the gases, between gas and air chequers is a criterion of efficiency. Gas chequers are less efficient in heat recovery (40-60 per cent. as compared with 70-80 per cent.). (iii.) The regenerators should be placed as near the ports as considerations of slag formation and disposal, and the life of refractories, permit. (iv.) The size and arrangement of brickwork is a compromise between requirements of mechanical strength and heat transmission surface. Thus, a small brick (2in. thickness) and a narrow opening may be desirable from the thermal standpoint, but impracticable for obvious reasons. In any case, the ideal reversal period is a function of the brick and its thickness (Fig. 3). The size of the brick must, also, bear a relation to the stand-by periods, cooling during week-ends, etc., as too much cooling then may cause slow working.

In a study of the published authoritative data on regenerators the author found[21] that using, as a basis of comparison, the average temperature drop of the waste gases, per lb. of chequer work, per cwt. of fuel burnt, per hour, was generally over 0.35° C. for open chequer work, 6in.×6in. openings, and under 0.4° for closer spacings, indicating less effectiveness, per unit weight of brickwork. In order to combine increased heat absorption surface, with an economical use of brickwork, special shapes have been proposed. Many instances of improved economy in the case of existing furnaces have been noted as due to increase of chequer surface, but the ideal ratio of free gas space to solid brick, for the various furnace capacities, is not known with any certainty, practice differing widely.

GEOMETRICAL FACTOR IN FURNACE EFFICIENCY.

It is in regard to the definition of this factor, that the technique of furnace construction retains the attributes of an art. All the fundamental laws governing the heat flow in the furnace involve the geometrical factor, expressed, for example, as the hydraulic depth of the gaseous streams in the convection laws, and if the whole problem were as simple as that for, say, confined ducts of such simple geometrical definition as a tube, more definite computation of furnace problems would be possible.

TABLE VIII.—SUMMARY OF TEST DATA ON REHEATING FURNACE TESTS (CHANDLER).

	Continuous Brick Recuperator.		Non-continuous Regenerative.		Continuous Metallic (Cast-iron) Recuperator.	
Reference No. in Fig. 6	9	10	11	12	13	14
Duration of Test, mins.	400	420	290	390	420	410
Hearth Area (length and breadth) ...	29×32ft.	29×32ft.	36×18ft.	36×18ft.	25×32ft.	25×32ft.
Rate of Output—						
lbs. per sq. ft. hearth area, per hour	49	53	51	63	69	82
Weight of Billets, lbs.	1,100, 650	650	1,120	1,300, 1,700	420	650
Heat Balance, Percentage						
Absorbed by Steel	63.07	58.29	40.91	36.47	47.3	57.41
Heat Loss in Cooling Water	1.14	1.53	—	—	2.17	1.59
Heat Loss in H_2O from H_2	2.64	2.73	4.31	4.45	3.55	3.10
Heat Loss in Waste Gases (dry) ...	17.56	18.13	22.39	22.08	26.24	24.72
Heat Loss in Radiation	16.48	14.54	34.60	32.56	20.74	13.18
Per cent. total heat returned by recuperation or regeneration	6.39	4.28	31.34	35.12	6.16	7.41

TABLE IX.—COMPARISON OF RECUPERATIVE GAS-FIRED AND COAL-FIRED CONTINUOUS REHEATING FURNACES.

	Producer Gas Fired Recuperative	Coal Fired.
Output—Tonnage, tons per hour	$12\frac{1}{2}$	2
Class of Material...	11in. sq. ingots	Small billets
Final Temperature of Material...	1,300° C.	1,100° C.
Fuel Consumption—cwt. per ton	2.58	2.0
B.Th.U. per ton × 10^3	326	292
Hearth Area, sq. ft.	621	100
Rate of Output—lb. per sq. ft. hearth area per hour	45	44.8
Heat Supply—B.Th.U. per sq. ft. hearth area per sec.	20.4	16.2
Heat Utilised—B.Th.U. per sq. ft. hearth area per sec.	4.7	4.0
Useful heat in material	23	24.7
Sensible heat in waste gases, including latent heat	22.4	30.4
Gas generation loss	15	
Unburnt combustible—ashes...	0.8	2.8
Unburnt gases	1.8	4.5
	2.6	7.3
Radiation, convection and other losses	37.0	37.6
	100.0	100.0

The variation of load, the importance of which has been repeatedly stressed,[22] is in itself a variable influence on the geometrical factor. The degree to which this factor is effective in comparison with variations as between a number of different types of furnaces is indicated in Fig. 6. The numbers placed against the different curves are references noted in the key, and in Tables VIII. and IX. of data of test results.

Apart from variations due to differences in the type of furnaces, and their manifold characters, it is remarkable how definite is the general relation between thermal efficiency and the degree of utilisation of the heating surface.

Careful study of the data given in Table VIII. in relation to the position of the points 9-14, in Fig. 6, will reveal that, apart from the geometrical factor, the distinct advantage of the continuous recuperative type is not due to the differences in type of heat recovery. Actually, the proportions of heat returned to the furnace by the recuperators are, relatively, low compared with the regenerator recovery of the non-continuous furnace. The main disadvantage in the regenerative, non-continuous furnace is the high radiation loss.

Again, in a most interesting comparison of a small coal-fired reheating furnace and a recuperative gas-fired furnace alluded to in Table IX., it will be noted that what the gas-fired furnace loses in gas generation loss, it recovers in improved combustion and heat recuperation, but, from the relative position of the points 15 and 16 in comparison with, say, Nos. 9, 10, 13, 14, one would conclude that it has some relative defect in lagging, recuperator efficiency, or geometrical feature, such as height of crown, passage of hot gases between the ingots, door leakages, etc., which disadvantage, the other furnace does not have. Such are instances of the types of comparison, necessary to give adequate assessment to the relative importance of the different factors in furnace operation and design.

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1. See "Fuel Economy and the Measurement of High Temperatures," by Sir R. A. HADFIELD, World Power Conference, Wembley, 1924.
2. Zeit ver deut. Ing., 58, 1017 (1924).
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Chapter 5.

POWER PRODUCTION IN IRON AND STEEL WORKS.

By John E. James.

Power production in iron and steel works is a problem of the most vital interest and importance to the industry, owing to its intimate bearing upon the much discussed question of fuel economy.

In these days, when we hear so much of coal and its economic utilisation, and reference is being made continually to the use of super-power stations and the general conservation of energy and sources of energy, the possibility of the more efficient and economical utilisation of the gas issuing from the blast furnace, with its associated potentiality, has apparently been forgotten, or not taken into account.

Large quantities of blast-furnace gas should continue to be produced, so long as iron and steel are required for the many and diverse uses to which they are put, and so long as the blast furnace remains with us as our chief method of producing iron. This gas, if properly harnessed, will prove a powerful factor in solving the problem of cheap power.

The conservation of the energy passing off from the blast furnace, in the form of gas, should appeal to everyone connected with iron and steel manufacture as a most important aid to the re-establishing of these heavy trades on a more prosperous footing.

The keystone of fuel economy, in any composite works, is the blast furnace, which must be regarded, not only as a producer of iron, but also as a producer of gas. The ideal fuel economy over the works as a whole is obtained only when, under normal conditions, no coal other than that required for the manufacture of coke is used. To achieve this means that the whole of the blast-furnace gas must be utilised to a very great degree of efficiency and that the maximum number of heat units, contained in it, must be converted into other forms of energy. Reduction of the coke consumption of the blast furnace, to the lowest possible safety working point, does not become of real importance until this ideal fuel economy is reached. When this point is attained, then coke consumption does become of paramount importance.

A fact not always realised is that the blast furnace is the most efficient gas producer to be found in industrial operation, and that blast-furnace gas is the ideal fuel for use in what is the most efficient prime mover, the gas engine.

The fundamental basis of fuel economy is the gas engine, with exhaust gas boiler, for both blowing and generating purposes, its use resulting in a greater percentage of surplus gas becoming available for other purposes, than is the case with the steam engine.

The installation of large modern gas engines for power production, combined with the complete and efficient utilisation of this much greater amount of surplus gas in the steel works and mills, accompanied by refinements in hot blast stove and heating practice, as well as the use of clean gas, is the direction in which fuel economy must be sought.

If the modern iron and steel works is considered as comprising essentially coke ovens, blast furnaces, open-hearth plant and mills, a study of the heat balance sheet of such a works shows that it ought to be possible to consume no coal, other than that necessary for the coke ovens. The output of blast-furnace gas and coke-oven gas, adding to these, where required, solid fuels of poor value, such as coke breeze, are sufficient to meet all the requirements of the works in mechanical and thermal energy. For the realisation of this, the minimum consumption of coal would have to be obtained, simultaneously with its most efficient utilisation.

The problem, however, is difficult from the point of view of balancing the various manufactures of the works, and something in the nature of a safety valve should operate, when, from any unforeseen cause, this balance is upset. This safety valve is, undoubtedly, a surplus of pig iron, since the gas available from this pig iron is of just as great a value as the gas from the pig iron used for steel making and is especially useful for meeting " peak " loads.

Many steel works on the Continent, despite the manufacture of a wide range of products, consume, under normal conditions, no coal for the production of finished steel other than that carbonised in the

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coke ovens, with the exception of locomotive fuel, and this is often avoided by the utilisation of electric and similar fireless engines ; at other works, coal is used to replace coke-oven gas which is sold to outside consumers because it yields a profitable exchange.

From this point of view of ultimate economy, the iron and steel manufacturer should be guided by the principle that blast-furnace and coke-oven gas be applied, primarily, to all uses where a solid fuel can not be utilised, and subsequently only to uses where solid fuel can give equally good or even better results, particularly under boilers. It is not economical to burn blast-furnace gas, or coke-oven gas, under boilers where coke breeze and the cheaper grades of fuel used in the pulverised state, or on efficient stokers, would give equally good results, whilst, at the same time, gasifying more expensive coal for use in heating furnaces, such as soaking pits and reheating furnaces, for which purpose blast-furnace gas mixed with coke-oven gas could be employed to greater advantage. It must be borne in mind that the use of blast-furnace gas and coke-oven gas, for heating and steel smelting purposes, saves the cost of gasifying in the producer an equivalent amount of higher priced coal.

Such efficiences can only be obtained by the installation of many refinements, involving the regulation of all gas pressures, so as to supply the gas under constant pressure at each point of consumption, with the air necessary for efficient combustion also under pressure, so that the whole process of combustion is under thorough scientific control. Coupled with this, is the preheating of both air and gas.

The utilisation of efficient and cheap insulating bricks and materials in the various metallurgical furnaces and heating appliances, gas mains and flues is, also, one which must be thoroughly considered in this direction.

Potential distributor of power.

To attain ultimate economy as a whole, the iron and steel industry should be regarded, as on the Continent, not only as a producer of iron and steel, but also as a potential distributor of gas and power to neighbouring industries, public utility companies and townships.

Most of the important iron and steel works on the Continent are coupled up with collieries and public utility concerns, both with regard to gas and power supply, thus enabling steel works and rolling mills without blast-furnace plants, to purchase the whole of their power cheaper from the large public power stations than they could possibly produce it themselves.

This broader outlook upon the fuel economy problem, influences the selection of the various gases for specific purposes and widens the field of their commercial application. It not only offers possibilities of reduction in cost of manufacture, but is a deciding factor in giving new values to industrial sites. This is proved by the fact that merchant pig-iron operations have been made profitable in locations where, without the utilisation and sale of their blast-furnace gas and coke-oven gas, in some form or other, they would have suffered severely in competition with blast furnaces connected up with steel works.

Although the commercial value of coke-oven gas has been fully realised, that of blast-furnace gas has not been generally appreciated, yet, despite the low heating value of blast-furnace gas, it produces, for every ton of coal consumed in the blast furnace, in the form of coke in the manufacture of pig iron, a surplus thermal value more than double that of coke-oven gas from a ton of coal, converted into coke.

The fact that the necessity for economising with blast-furnace gas has not been generally appreciated, is due, principally, to its low heat value, which makes it, apparently, unsuitable for metallurgical purposes, except where its calorific value is increased to 150 B.Th.U.'s by enrichment with coke oven gas, tar or oil, and although most blast furnaces linked up with steel works pass their surplus gas on to other departments, much of this is used with a low degree of efficiency.

In the most up-to-date practice, only 25 per cent. of the total output of blast-furnace gas is required for heating the blast. If gas engines are used for blowing and generating purposes, 18 to 20 per cent. of the total gas output will be required for blowing, pumping and power required by the furnace plant as against 40 per cent. with the steam turbine. This leaves 50 per cent. of the total gas as surplus in the case of the gas engine, and 30 per cent. in the case of the steam turbine, after deducting 5 per cent. to cover gas losses throughout the plant.

In the case of a three-furnace plant, producing 1,500 tons of pig iron per furnace per week, and 182,000 cubic feet of gas, per ton of pig iron, this surplus gas will, if utilised in gas engines for the production of electric power, provide a supply of 21,000 kilowatts, including 3,000 kilowatts produced from the steam recovered from the exhaust gas boiler, by utilising this in an efficient turbine, available for distribution for uses outside the requirements of the furnaces themselves and their auxiliaries; whereas, with the steam turbine, this surplus power will be 10,000 kilowatts.

There is no doubt that the modern steam turbine is capable of high efficiencies, if of sufficient size and provided with a most efficient boiler plant. Modern power stations containing units of from 50,000 to 75,000 kilowatts, operating with steam pressures of 500 lbs., per square inch upwards, and 250 to 350° F. superheat, claim to generate 1 kilowatt-hour with, approximately, 1 pound of coal. These results compare very closely, in overall heat efficiency, with that of the gas engine plant, but to attain such efficiencies the steam plant must be of huge capacity, and is, to all intents and purposes, as complicated an installation as the gas engine plant, with waste heat recovery units.

It has, however, the disadvantage of size which places the scope of its use only within large distributing companies, whereas the 10,000 H.P. gas engine can easily obtain the same efficiency, and comes within the scope of use in the iron and steel works.

Efficiency of gas engine.

The initial cost of the gas engine is now nearing that of the turbine and boiler plant, and experience has proved that the efficiency of the gas engine, as compared with the steam turbine of capacities suitable for iron and steel works, is 2 to 1. The modern gas engine has been well developed, not only in regard to size (units of 11,000 H.P. driving 8,000-kilowatt generators now being built), but particularly in the recovery of the waste heat carried by the exhaust gases and cooling water. Gas engine stations now usually operate with efficiencies of from 30 to 33 per cent., the efficiency in the latest practice reaching $37\frac{1}{2}$ per cent. The cost of cleaning additional gas for the gas engine, in these days, involves but a small extra expense, as it is quite fully realised, in modern practice, that the whole of the gas must be cleaned if the best results are to be obtained at stoves and boilers.

The modern trend in fuel economy in iron and steel works practice is towards the most complete and thorough utilisation of every source of heat, potential or, so called, waste, even at the cost of large capital expenditure, since the economies effected should balance in a few years the first cost of installation.

This means the most efficient and the economical use of blast-furnace gas and coke-oven gas, and the most complete and thorough recovery of the latent heat contained in the waste gases from all metallurgical furnaces, gas engines with boilers and in the exhaust steam from all types of steam engines.

The ideal combination for power production in an iron and steel works would appear to be to produce the whole of the blowing power by gas engines, all equipped with exhaust gas boilers, and to produce 50 per cent. of the generating power by similar engines, and 50 per cent. by steam turbines, these turbines being run by the steam produced by the exhaust gas boilers attached to the gas engines and by waste heat boilers fitted to all steel furnaces, soaking pits and reheating furnaces.

This combination provides, not only the elasticity and flexibility so highly necessary, but also sufficient power to drive electrically the rolling mills and auxiliary machinery on normal full output capacity. It is not only an ideal, but a convenient combination, since it adapts itself to the requirements of the steel works and rolling mills, as, owing to the mills not being operated during the week-ends, the turbines, generating power from the waste heat of the mill furnaces, are not required at such periods.

The advantage of cleaning the whole output of blast-furnace gas to a degree of cleanliness of 0.050 grammes, per cubic metre, will also have to be seriously considered, not only because of its great advantages in gas engines, but also in hot blast stoves, enabling the adoption of minimum brick thickness and small checker openings, so that very much larger heating surfaces can be developed for a given size of stove, and, further, because gas of this degree of cleanliness is suitable for use for coke ovens and heating furnaces, where gaseous fuel, low in calorific value, is applicable.

This gas, due to its high percentage of inert matter and low flame temperature, is ideal for heating long combustion chambers and systems of flues, combining a long flame with mild and uniform heat. Operators of coke ovens, using coke-oven gas, and also those using producer gas, akin to blast-furnace gas in heating value, find it easier to maintain uniform and steady temperature in their flues with blast-furnace gas than with coke-oven gas. More accurate temperature control is obtained, due to the fact that, approximately, equal amounts of gas and air are required for combustion, and, further, because the fluctuations in heat value, due to alteration in composition of the furnace gas, are of a much smaller degree than is the case with coke-oven gas, especially if the gas is being supplied from more than one blast furnace.

Blast-furnace gas is being widely used on soaking pits and reheating furnaces, and excellent results are being obtained with preheated or regenerated gas, where finally cleaned gas is now being used in preference to producer gas, as this results in cleaner checkers and increased furnace life.

Blast-furnace gas is too low in heating value and too high in inert matter for smelting steel in the open hearth furnace, for which purpose it must be enriched by mixing it with coke-oven gas, tar or oil, but greater economy can, undoubtedly, be effected by using each gas separately wherever possible, applying them where they give the best results and the best returns.

In this connection it would seem that coke-oven gas should be utilised in place of producer gas for steel smelting, in view of the high temperature required in this process, for which the high combustion temperature of coke-oven gas is eminently suitable. It may, however, be necessary to use a mixture of blast-furnace and coke-oven gases for this purpose, in order to maintain the heat balance of the works as a whole.

Isolated blast-furnace plants, unconnected with steel works, have no outlet for their surplus gas in their own works, hence, they naturally use their gas under boilers for the generation of the power they require for their own operations.

Under present conditions, such plants are not connected to neighbouring industries and public utility concerns. They have an ample supply of a cheap source of power, at present going to waste, which ought to receive the fullest possible consideration in these days when we hear so much of national electricity schemes for the production of cheap power for all. These plants afford an excellent opportunity for the large gas engine installations, as a means of supplying cheap local power, by connecting up to existing power distributors, thus saving the power they are now unable to harness.

I have endeavoured to show the value of the coke oven and the blast furnace combined, as the cheapest form of gas producer known, and that they can if properly harnessed, and the gas efficiently distributed, provide heat and power for large industrial areas, eliminating almost entirely raw coal, and giving in its place valuable by-products, domestic and industrial gas and cheap power. In this way they would be enabled to pass on to the metal industries, pig iron and steel at low cost, whilst, at the same time, preserving national safety and independence, as well as enabling employment to be better stabilised, by the more general use of the metal industries, as one of the ready and convenient methods of exchanging effort for need in the world's markets.

In our own country, we are still dependent upon our metal industries as a means of providing the largest amount of employment of any of our industries. Our climate, geographical position, and particular skill of our people in metal working, all point the way to the fullest possible development of these industries by all that science and public encouragement can bring to bear upon them, if we are to maintain the standard that post-war conditions have imposed upon us. Neither should this purpose be deflected by any small minority attempting or pre-supposing that these industries can be maintained, with any degree of safety or certainty, from outside sources of raw material supply.

I regret to have to admit that the use of the coke ovens and blast furnaces, as a means of providing cheaper fuel and power to the iron and steel industries, is not making the same progress in this country as it is in the competitive countries of the world. Striking evidence of this is obtained by the annual tonnage returns of the pig iron industry of Great Britain. From these it will be seen that we have, almost entirely, lost our export market, and also that large quantities of imported pig iron are now being used in our steel works and foundries, so much so that, speaking in general terms, I would not be

surprised if, when the final returns for the year 1927 are issued, it will be found that we are dependent on "outside sources of supply" to the extent of nearly 50 per cent. of our total requirements, which will have been imported in the various forms of pig iron, billets, bars, joists, plates, etc.

So far as pig iron is concerned, its quantitative importation into this country is entirely a post-war condition, and is growing with alarming rapidity. If the progress of these basic industries continues to develop on the lines I have indicated in all other countries but our own, without some definite challenge from us, they will establish such a lead in the modernisation and development of their plants, that those of ours which are at present standing idle will be obsolete and incapable of restarting or manning. This latter point of man power should not be forgotten, as these plants would demand a much greater amount of labour, and of a character difficult to find with sufficient training, to produce any reasonable degree of efficiency or output.

From their present position, I can only conclude that other countries have more fully realised the importance of their independence for raw material supplies, as well as the national value of coke ovens and blast furnaces, and that they are determined to maintain them at the highest possible state of efficiency, both in regard to output and, also, as power producers, even if the resultant product, in excess of their home requirements, has to be disposed of at a price that admits of no profit, or even a loss.

Chapter 6.

FUEL AND ENERGY CONTROL IN IRON AND STEEL WORKS.

By H. C. Armstrong, A.M.Inst.C.E.

Force of circumstances has caused considerable interest to be taken in all new means to further economy in fuel consumption. New designs, a closer study of the common laws of the physics of heat engineering, and the pressing needs of industry for cheaper production, are combining to urge attention be paid to the study and control of fuel problems. The gradual development of organisations inside the works with a view to improvement in fuel consumption has necessitated the close and careful control of fuel usage under scientific methods and in trained hands.

The fact that little has been done in Great Britain in this direction only indicates the considerable economies to be obtained by its adoption. Elsewhere, especially in France and Germany, the conducting of all heating operations are carefully controlled by a specially trained staff. Heat energy is looked upon as a highly valuable asset which cannot be allowed to become uselessly dissipated.

The operation of metallurgical heating furnaces lend themselves peculiarly well to scientific control. That is, to accurate measurement and observation of heating conditions which, following the natural laws of physics, are simpler than apparent at first sight.

It is essential to organise in every works a regular and constant control of all fuel-burning plant. This control is as necessary as is the careful keeping and checking of accounts, but is frequently not considered in this light. Actually, comparatively insignificant items are closely watched to prevent waste, while a large and constant loss of fuel, owing to bad combustion conditions, is allowed to go on unchecked.

Efficient control of fuel combustion must be entrusted either to a special fuel economy department, or to an engineer trained in the knowledge of combustion and solely occupied with questions of heating. An engineer in such a position, moreover, must possess a considerable amount of tact in addition to technical knowledge, including a chemical outlook on combustion and all it entails. Enquiries into every question of fuel economy quickly become wrapped up in so many other matters as to render imperative a knowledge of the needs of the process under consideration.

Much doubt will be thrown by others on the work of the combustion engineer until his work is properly understood, one great difficulty being the inclination to think the results are small in comparison with other costs. Energy in the form of heat enters into every process in an iron and steel works. Heat units may be considered analogous to electrical units. It is no more permissible to waste energy in the one, than in the other. The electrical unit is comparatively small, yet is accurately gauged, watched, and accounted for. How different is the method where the heat unit is concerned. The French Fuel Consumption Commission[1] very carefully studied the question of the correct training of combustion engineers, and pointed out how essential it is, if improvement in fuel use is to be made, that the proper technical knowledge of heating shall be possessed by the staff. They even went further and suggested that at the time there was great difficulty in obtaining a sufficiently competent higher official.

A great hindrance to the satisfactory burning of coal and correct treatment of all heating problems is the scepticism which is often shown by the manufacturers, and even by works' engineers, who have a very imperfect idea of the economy which may be effected in fuel consumption by using a better system, and who overlook the constant losses of heat around them through long familiarity with such conditions.

In the pages of the present work the best types of heating plant are fully explained; still the process of replacing out-of-date furnaces, etc., is a costly one, and must naturally be a lengthy one. Economies in the working of all plant, however crude, can be obtained by correct methods of control. All endeavours in this direction in France, Germany and in this country, have resulted in savings, some as much as 30 per cent., others less, but 15 per cent. at least may be looked for. This represents an important proportion of a year's coal bill in a big works.

(1) French Fuel Consumption Commission, 7th Report. The organisation of Industrial Fuel Economy. Journal Officiel de la Republique Francaise, 20th August, 1922.

Methods of measurement as directly applied to metallurgical furnaces.

Important as it is to employ the various recording and other instruments now available, these are of very little use unless full advantage be taken of them. Disappointment at the poorness of results obtained can usually be attributed to failure to understand the lesson taught by the instrument readings, and, or because of, the absence of the trained personnel to point out such lesson and to apply the teaching. As an example, high temperature of the flue gases of a boiler may be due to dirty tubes (scale), leaks in cross flues, or overloading. Circumstances will point the reason and fix the responsibility.

Before installing any instruments the advisability of their use and their probability of success must be fully considered. Whereas a CO_2 recorder fitted to show the composition of boiler flue gases is of high value, such an instrument attached to a re-heating furnace will be of little use. The effect of extra air drawn in at door openings, or through faulty damper fittings, is sufficient to confuse the issue entirely.

Where furnaces are gas-fired, it is essential that the necessity of constant gas pressure as well as constant quality be realised, and pressure recorders should be attached to the producer. The connection between gas pressure and gas quality is so close on a steam-blown producer as to render a pressure record a tell-tale of the highest value. Coal-fired furnaces may be said to require no instruments unless pyrometric control is necessary; although it may be observed that fuel economy is generally greater where pyrometers are in use. This follows from the fact that heat exchange depends upon temperature difference. Furnace design governs the maximum temperature obtainable, and any fuel added in excess cannot cause further heat exchange, and must be waste.

Measurement of the amount of fuel used in all furnaces must be made if accurate control in any form is to be made. It is most noticeable in many works, otherwise excellently conducted, how carelessly coal is accounted for, whilst the use of other articles, such as lubricating materials, stores, etc., are watched. It is a simple matter, either to fill bunkers to the same level at the end of each week, or to take account of the amount left in. Mr. J. E. Lea has pointed out that the size of coal has practically no effect on its weight per cubic foot. A cubic foot of coal may be taken, for all practical purposes, as weighing 48 lbs.

Thus the necessary data for the control of all furnaces are easily obtained, and comprise:—

(a) The amount of fuel used.

(b) The quantity of material heated, or throughput.

(c) The furnace hours.

Weekly returns should be made with as little delay as possible, so that errors may be checked and any unusual variation enquired into before the incident is forgotten.

Furnace hours are understood to be all the hours during which fuel is being burnt whether the furnace be charged or not, and must include "lighting up," or preparatory heating periods. As will be seen later, fuel is burnt at the same rate during these periods. Figures taken for short-working periods have no real meaning. The only difficulty may be caused by the recording of the last of the above data. In many operations, especially in the forge, it is by no means an easy matter to compute the total weight heated owing to the number of re-heatings necessary to complete the task. For instance, in the heavy trades it may be necessary to re-heat and then to turn the piece, and re-heat again before the finished forging is completed. What weight is to be taken to represent the "quantity of material heated"? Fortunately, as will be seen from the methods suggested in the following, a simple estimation will suffice.

Characteristic furnace curves.[2]

Various methods of expressing the behaviour of furnaces have been put forward from time to time, all of which lack the possibility of real comparison being made between furnaces of different types, or of establishing anything to be taken as "standard practice." Thermal heat balances mean little to the shop superintendent. Furnace efficiencies vary with the furnace load. Fuel consumption per square foot of hearth area, useful to the furnace designer, means nothing if the output varies. The commonest of all methods,

(2) Characteristic Curves as an aid to Fuel Control. H. C. Armstrong. Circular by National Federation of Iron and Steel Manufacturers, May, 1927.

that of expressing fuel used in some weight, such as hundredweights, per ton of product, is the most misleading, and not only reduces comparison to an absurdity, but is the reason for neglect to improve matters, owing to the difficulty in making comparisons of any value between one's own practice and that of another country, or of even a neighbouring concern.

A study, however, of the conditions operating in any furnace will show that, by checking the amount of fuel burnt over any period or heating cycle, a constant can be arrived at and, under control, fixed and watched. The fuel burnt per hour is easily reckoned, is the simplest of units, and, as a practical means of control, is a highly reliable guide. The essence of furnace economy is to keep the fuel per hour as low as

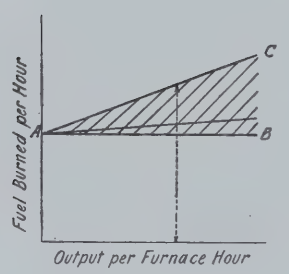


FIG. 1.

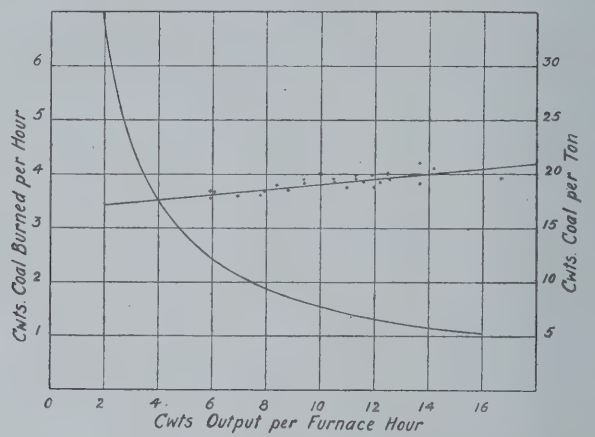


FIG. 2.—*Weekly results from furnace supplying Forging Hammer.*

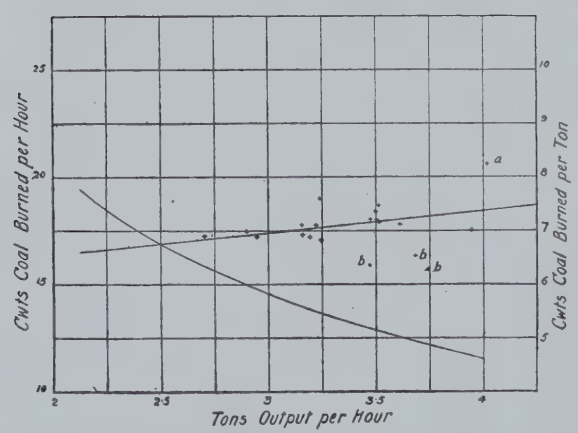


FIG. 3.—*Weekly results from combination of furnaces supplying Rolling Mills. Point 'a' was obtained when using inferior coal. Points 'b,' 'b,' 'b' are results from special conditions.*

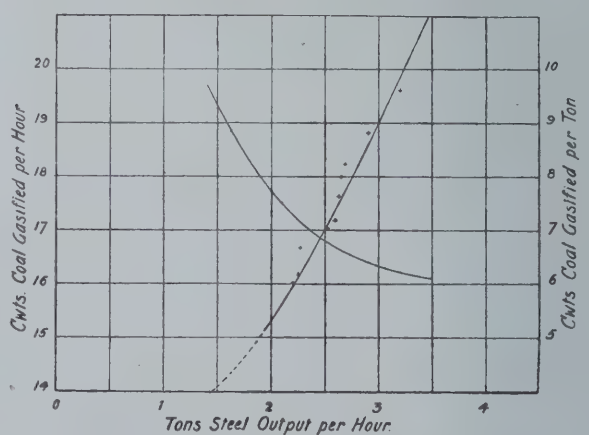


FIG. 4.—*Weekly results from Siemens Martin Melting Furnace.*

possible. By plotting the output per furnace hour against the fuel per hour, or if preferred, the fuel burnt per ton of output, a "characteristic" curve can be drawn to illustrate this, and the operating efficiency of any furnace kept under constant observation.

If it is assumed that the furnace has to work at a constant temperature whatever the work being heated then the losses due to radiation will be constant. A constant amount of fuel (from which a large amount of the heat is carried away by the waste gases) must be burnt to overcome this loss whatever the loading. In Fig. 1, the horizontal line AB may be taken to represent the amount of fuel that is necessary to keep the furnace up to its correct temperature, which must be the same for all loads.

More fuel is required to heat up the charge, the quantity of which must be roughly proportional to the amount of material heated, although a further expenditure of fuel, unfortunately, causes a further loss in waste gases.

The hatched portion on the figure represents the additional fuel required for the charge, and the line AC the total amount necessary for any loading. This enunciation is borne out in practice, and curves, which for all practical purposes may be taken as straight lines, can be drawn for all furnaces. With very few results it is possible to draw a basis curve for control, which can be re-drawn from time to time as improved methods of working or design render possible a lower and improved basis.

FIG. 5.

As any fresh result lower than the curve must indicate less fuel used, not only is it possible to stop wastage, but results of alterations are immediately noticeable, and complete control can be kept, week by week, of all furnace operations as easily as it is done in any repetition machine shop. Rightly interpreted, the results are highly valuable for many reasons.

Wastage is stopped and coal saved, different qualities of coal can be tried and compared, the effect of changes in design noted, variation in heating methods tried, all alterations, great or slight, noted in accordance with their economic value, and many other lessons learnt, which are bound to lead to economy in fuel.

Although the universal habit of expressing coal consumptions in so much fuel per ton is not so indefinite in those trades where the work is entirely repetition, and the consumption per ton of product varies little from time to time, any variation in output will quickly upset the usual figure. The "best" figure obtained under the most favourable conditions is apt in practice to be quoted as the normal figure. Systematic charting of the results will show the truth.

In the heavy trades, such as are followed in the Sheffield district and elsewhere, the very nature of the work precludes repetition. Steel forgings vary greatly, whether being cogged from the ingot, or in the final stages, and a large divergence in output occurs even from the same furnace. Under such difficult conditions fuel figures per ton are not comparable, and control on such can only be unscientific and haphazard. On the other hand, for the reasons explained, the *fuel per hour* varies but little for large differences in output, and then in strict proportion.

Figs. 2 and 3 indicate the results from the operation of furnaces plotted on these lines. The "straight line" law shows very clearly; also, the very small increase in the fuel burnt per hour for a comparatively much higher output.

Plotting the same results as fuel per ton against output per hour, a hyperbolic curve is obtained, which gives the manager a means of watching the weekly results, and indicates the importance of keeping the output high in order to reduce the fuel cost per ton as much as possible. Charts drawn on these lines are hung in the superintendent's office and interest quickened among all concerned. This done, fuel is regarded from the proper perspective. Without some such method everything is subservient to "labour charges" and coal costs relegated to the background as of little importance.

Using such "characteristic curves," the combustion engineer is enabled to fix bonus payments to his firemen if so desired, and to place his finger at once on any losses or sudden changes otherwise neglected.

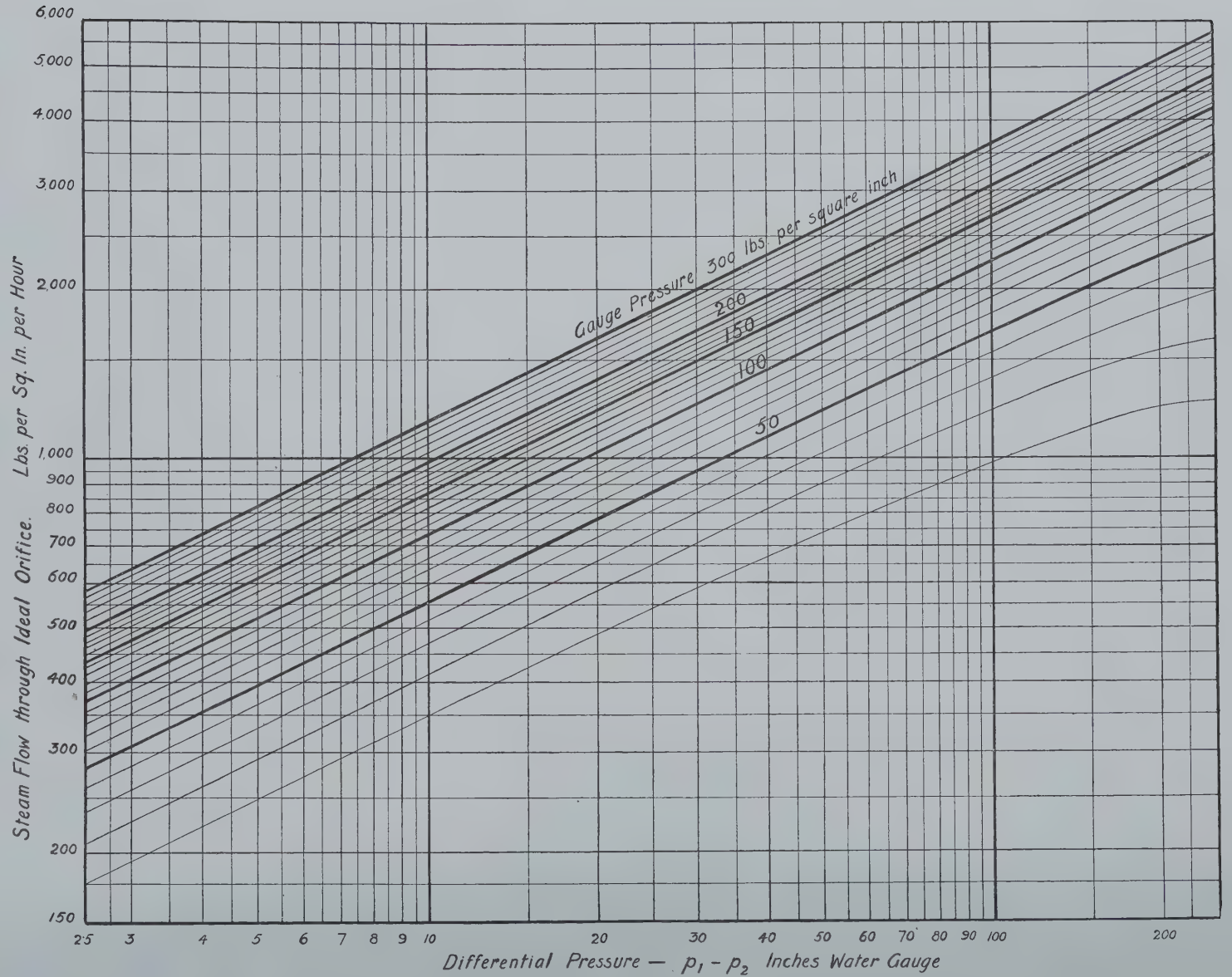

Steam Flow through Ideal Orifice. Lbs. per Sq. In. per Hour
6,000
5,000
4,000
3,000
2,000
1,000
900
800
700
600
500
400
300
200
150
Gauge Pressure 300 lbs. per square inch
200
150
100
50
2·5
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
200
Differential Pressure — $p_1 - p_2$ Inches Water Gauge

Fig. 6.

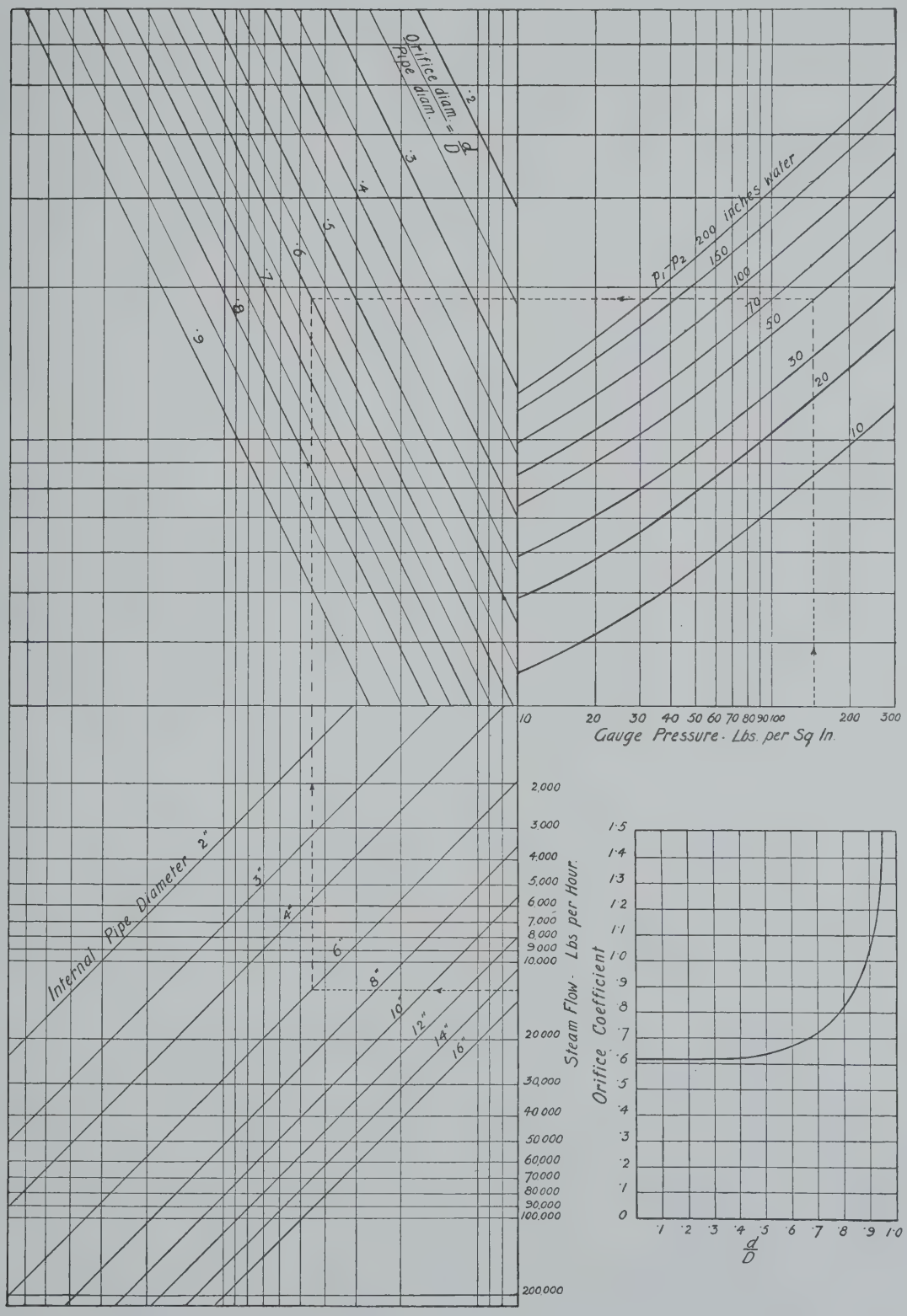

Orifice diam. = d/D
Pipe diam.
.2
.3
.4
.5
.6
.7
.8
.9
p1-p2 200 inches water
150
100
70
50
30
20
10
10 20 30 40 50 60 70 80 90 100 200 300
Gauge Pressure - Lbs. per Sq In.
Internal Pipe Diameter 2"
3"
4"
6"
8"
10"
12"
14"
16"
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
200,000
Steam Flow - Lbs per Hour

FIG. 7.

Orifice Coefficient
1·5
1·4
1·3
1·2
1·1
1·0
·9
·8
·7
·6
·5
·4
·3
·2
·1
0
·1 ·2 ·3 ·4 ·5 ·6 ·7 ·8 ·9 1·0
d/D

FIG. 8.

Whenever possible, it is advisable to determine the weight heated, or true throughput of the furnace. Owing, however, to the fact that the fuel per hour varies very little with the loading of the furnace, these curves approximate closely to rectangular hyperbolae, also the proportion of " finished production " to weight heated, following the laws of probability, varies but little from week to week. It follows, therefore, that the necessity of obtaining the exact weight heated becomes of minor importance, and it is sufficiently accurate to plot the production figure. This obviates the necessity of taking into account the number of times a job may be re-heated, and is much more convenient.

From these curves the fallacy of using the fuel per ton as a means of comparison of the heating efficiency of furnaces will be seen. Low fuel consumption per ton may be the result of a good furnace, or merely of a large " divisor " owing to the advantageous output. Such figures are never comparative unless the output is taken into consideration. It is the duty of the combustion engineer to lower the one, of the manager to improve the other.

This method of controlling the operating efficiency of furnaces can also be applied very usefully to melting furnaces. Fig. 4 indicates the results from a Siemens open hearth furnace making special steel from cold charges. The inclination of the straight line, fuel per hour, curve shows that the efficiency of the furnace does not increase for the higher loading to the same extent as is the case of a simple re-heating, or annealing furnace. A drop does occur in the fuel per ton when the output increases, but fuel control is of greater importance by comparison.

Close investigation shows the gas used per hour may be divided into two rates, that consumed when the furnace is getting ready, or between tapping and charging, and that during which the charge is in the furnace. As the conditions of heat transfer should not, materially, alter from one charge to another, only the weight can effect the gas required. The only difference will be in the time taken, and the fuel per hour should be constant for all similar weights, and proportional for others. Thus, with the aid of characteristic curves drawn for the melting furnace, a check can be kept on the quality of the gas made even without instruments at the producer. Delays in working, or excessive repairs, will also be revealed in the same way. A close comparison between cold and hot metal working can also be made.

On the same lines, *i.e.*, observing and plotting, the fuel used per hour can be governed in almost all heating processes in iron and steel manufacture. E. C. Evans has applied a somewhat similar method to the blast furnace with very satisfactory results.

Steam control.[3]

There is an important field for economy in the investigation of the steam consumption of the various units in an iron and steel works. Boiler control and the correct use of boiler fuel, already described in this volume, is of high importance. Nevertheless, attention to the distribution of the heat energy in the form of steam after it has left the boiler has been relegated to the background, owing, partly, to the paramount necessity of " keeping the plant working," and, partly, to the fancied difficulty of measuring steam as a practical proposition.

To overcome this latter some simpler form of apparatus for steam metering is necessary. That is, a simple fitment which can be applied in any position, and used in conjunction with one of the recognised steam meters.

It is well recognised that boiler operation, one of the most important duties of the combustion control engineer, is assisted by the use of instruments for measuring flue gas analyses, exit gas temperatures, chimney draught, etc. The firemen, properly taught, will look upon these as " friends." If such are not fitted, the steam pressure gauge by itself is not sufficient, and at least a flow indicator should be fitted to give the fireman an idea of quantities. The difference between pressure or quality, and quantity, is not sufficiently understood.

In a steel works, steam losses may be divided into those caused by :—

(a) Radiation from exposed surfaces.
(b) Wetness.
(c) Steaming of unnecessary mains.
(d) Leaks through loose fitting valves, drains, etc.

(3) Measurements of Steam Flow in Works Practice, T. Nordenson and H. C. Armstrong. Institute of Fuel, Autumn, 1927.

Radiation.

Radiation from considerable lengths of unlagged pipes and flanges is a source of much loss in a steel works. The constant vibration in a shop where hammers are working necessitates special means being employed to prevent lagging from being shaken from the pipes.

Wet steam.

Wet steam is known to cause trouble to packings and glands. It is additionally necessary where large hammers, or presses, are supplied from the boilers, to take means to ensure that the steam is dry. Owing to the sudden demands made on the boiler, the pressure-drop over a very short period is considerable, and violent ebullition takes place, causing water to be mechanically carried over with the steam.

Unnecessary mains.

The ramifications of a large steel works frequently necessitate steam being carried long distances. In designing the mains valves should be placed so as to permit of the cutting out of sections not in use at any time.

Leaks.

Leaks through drains and stop valves being, for convenience sake, led through pipes out of the general sight, are lost to view. Leaks through ill-fitting hammer valves may become very serious. Tests carried out in different works show surprising quantities of steam being passed unrecognised through the exhaust. A 5-cwt. tilt hammer required a flow of 300 lbs. of steam per hour to work it, but when measured the total flow of the hammer was found to be at the rate of 1,200 lbs., per hour. In another works, although the hammer was not actually hammering, over 5,000 lbs. of steam were found to be passing on a ton hammer when the operative valve was in a certain position. Many other cases could be cited. There is a great tendency to "barrel" in all piston valves serving steam hammers owing to uneven wear in one position. This is, probably, accentuated if the steam be very wet, when the oil film is removed from the inner surface and erosion occurs. A new type of hammer valve to overcome this is urgently required, and will be forthcoming if the practice of the measurement of steam in steel works increases.

Fuel economy has been spoken of as the sum of a large number of small savings. Nothing offers a greater scope than the measurement of steam, and the latter must be considered as valuable in a steel works, where steel demands are heavy, as the everyday accounts for any of the materials used. The principles of flow of steam through pipes and of steam measurement have been explained by Hodgson,[4] Backstrom and others. Backstrom has published graphs[5] which save a deal of laborious calculation from which coefficients can be read. These are of very great assistance to the works engineer.

The illustration, Fig. 5, shows a very simple orifice fitting which can be used with these graphs. This fitting satisfies the demand of the engineer for simplicity, and can be inserted in a pipe between flanges with the minimum of labour. Being only $\frac{1}{2}$ in. thick, very little springing of pipes is necessary. The large diameter is made so that it fits inside the bolt circle, the only alterations required being slightly longer bolts through the flanges. As in all steam measurement, the orifice must be placed in a length of straight pipe, care being taken to avoid bends, tee pieces, or valve fittings. The actual orifice plate is of 3/32 in. steel plate, preferably of stainless steel.

The cooling chambers are made of small section, high-pressure copper pipe, bent in the plumber's shop into coils about 8 in. across, with standard unions soldered on with silver solder. Connections of the same material are made to the recording instrument, care being taken to keep these coils horizontal. It only remains to blow all air from the pipes, turn on steam, and, in a few minutes, condensation fills up and the pressure differential between each side of the orifice is registered.

(4) "The Commercial Metering of Air, Gas, and Steam." Minutes of Proceedings, 1918, vol. cciv., page 108. Inst. of Civ. Eng. J. L. Hodgson.

(5) Angmatningar. Matts Backstrom, Teknisk Tidskrift Mekanik, 1920, Haft 7.

Although in the majority of cases, especially for cost accountancy purpose, it is preferable to have an integrating attachment on the meter, should a constant record not be required, observation can be made with a manometer which is either built up at a low cost from standard fittings or purchased ready made.

The method of calculation form Backstrom's graphs, a set of which, calculated for a sharp-edged orifice, have been translated into British units and reproduced in Fig. 6, is as follows:—

The suitable size of the orifice plate is first obtained. To do this it is necessary to make a rough approximation of the maximum amount of steam passing through the pipe to be measured, and to decide what the differential pressure of the instrument being used will allow. Following the dotted line on Fig. 7 in the direction of the arrows, the sequence steam flow-pipe size, produced vertically, intersects the horizontal from the gauge pressure-maximum differential line where diagonals are drawn, giving the required ration of the orifice and pipe diameters. It is important that this ratio, from which the size of the orifice opening is obtained, be not greater than ·8.

The orifice, thus designed, is than fitted, and it remains to translate the differential readings obtained into actual quantities of steam flow. For this, the diagram Fig. 6, which gives the theoretical flow per square inch of an ideal orifice, is used. Reading upwards from the differential pressure to the steam pressure, and across horizontally, the rate of flow is obtained, which must be multiplied by the orifice area and a correction coefficient. This is obtained from the small graph, Fig. 8, where it is plotted against the ratio, previously referred to, of the two diameters.

If these charts are plotted on a larger scale and kept to hand, steam measurement will occupy but a short time, and will, invariably, lead to beneficial results, and incidentally to a closer study of the fascinating subject "steam."

Space, unfortunately, does not permit of the description of any further means of control, but it must be remembered that the success of any system of fuel control will depend upon the ability to visualise heat as a real quantity, and to measure, on all and every occasion, the amount being used. Scientific control means no more, and no less, than this.

The duties of the combustion engineer are many and, once realised, will grow as full control becomes an established fact in all iron and steel works.

Chapter 7.

PULVERISED FUEL IN METALLURGICAL INDUSTRIES.

By Leonard C. Harvey.

It is estimated that 15,000,000 tons of coal in pulverised form are now used per annum in American metallurgical works, resulting in an all-round saving of at least 20 per cent. in fuel; the utilisation of inferior or small coal in place of high-grade lump coal; a very considerable reduction in labour costs as against hand firing; and other incidental economies.

In Great Britain, economy in fuel consumption by the same means is fast becoming a well-established practice at power stations, but the wider metallurgical field still remains undeveloped to a great extent.

There are it is true many circumstances to which the metallurgist must give careful thought before making any radical departure from firing or heating conditions as they exist on his particular furnaces, and one of the most important considerations is the effect that any new method of firing may have upon the quality of the product. It can, therefore, be understood that all reasonable caution should be exercised before any drastic change in fuel application or furnace design is made.

In America the number of pulverised coal installations at metallurgical works, both for furnaces and boilers, is now, approximately, 300.

Several of these larger plants, nearly all of which embody the "central mill system," have cost over £100,000, and in the majority of cases for smaller works between £20,000 and £50,000 for equipment and alterations. It is moreover usually expected that the total return upon capital expenditure will be sufficient to recover the whole cost of the plant well within three years.

A full description of the central mill plant has been given in Chapter 1. The installation for metallurgical works is to all intents and purposes the same as for power-house requirements; the fuel transport lines alone being longer in order to reach out to the different departments of a works, and the storage bunkers are more widely distributed. An illustration of a small central mill plant erected at a British malleable iron works is shown. The fuel distribution pipes can be clearly seen. For large works this method enables one to concentrate coal supplies at one convenient spot, while it eliminates traffic congestion and the shunting of coal waggons and all attendant internal distribution costs. Coal distribution costs have been accurately recorded by works engineers, and in a large works figures have been given which show that these represent an average charge of 2s. 6d. to 3s. per ton in certain cases.

The unit mill.

Although the central mill system has been adopted so generally at the iron and steel works throughout America, it is a very significant fact that the small self-contained unit mill has been installed with considerable success in France and Germany. The principal objections usually advanced against the use of these machines are inflexibility and high cost of power and maintenance. These considerations are dependent, to a large extent, upon the type of mill used, the grade of coal, and the nature of the application. Beneficial results have, however, been realised by this form of firing in a large number of German works with unit mills. Reliable records of maintenance costs show a figure as low as 1d. per ton for soft lignite fuel, to as high as 1s. 2d. per ton of pulverised anthracite coal. The normal cost for maintenance of unit machines and equipment installed should not exceed 3d. or 4d. per ton of ordinary bituminous coal pulverised. Anthracite, and any abrasive hard fuel such as gas works' coke breeze, will naturally increase both the power absorbed and the maintenance costs.

In the opinion of the writer a mistake has been made in requiring the high speed unit mill to fulfil the function of a breaking-down crusher as well as that of a pulveriser, the beater elements thus being taxed to destruction. Hard lump coal should be pre-crushed in slow running rollers and only the final stage of pulverisation accomplished in the unit machines. The power consumption for unit mills, reckoned at the burners of furnaces, has been as high as 30 kw. per ton of fuel burned, but progressive improve-

ment in design has reduced this figure very considerably. A basis figure of 15 kw. for bituminous coal may be assumed with safety when making preliminary calculations. Unit mills can now be obtained for operating continuously with coal containing up to 15 per cent. of moisture. Coal when ground in a central mill house must be dried to within 5 per cent. of moisture, transported through small diameter pipes by pressure, and held in storage at the furnace bunkers. Undried coal of higher moisture content will pack in the transport lines and is liable to spontaneous combustion if held for any length of time in bunkers. The self-contained unit system has this advantage over the central system, that comparatively wet coal can be pulverised and applied direct at the furnace, no dryers as a rule being required. For the more exacting operations, such as small nut and bolt furnaces, light forge furnaces, rivet heating furnaces, and for high temperature work in both large and small furnaces, the drying out of moisture in the raw coal is still necessary.

Combustion and ash.

The more confined the combustion area, the greater the necessity to obtain a high degree of fineness and uniformity of product, and the more perfect must be the intermixing of the fuel and the air supply prior to combustion. In all metallurgical work the greater the degree of intermixing, or turbulence, the better will be the results obtained. Burners embodying these principles are now available whereby dispersive or widely diffused projection ensures complete combustion within a comparatively short distance from the burner orifice, and under these conditions alterations to existing furnaces are slight. Actual ash deposit upon work heated or brought to a temperature approaching fusion, presents no great difficulties. In the former case the ash deposited is of a fine dusty character and can be blown or brushed off the metal. If the ash is fused, as in pile and faggot heating operations, the slag chills and cracks off in the first pass of the rolls, and no trace is found thereafter. The difficulties previously experienced with ash and slag on the work heated, have been so successfully overcome that pulverised coal firing has recently been extended to pipe strip welding, an application which demands high temperatures and perfectly clean and dust-free surfaces. The main features which have had such a marked effect upon the successful results now being obtained in metallurgical operations are fine and uniform pulverisation of coal suitable for the work in view. For most metallurgical operations a good quality coal is essential. Low-grade fuel, high in ash and low in price, may be used for suitable applications, such as boiler firing, kilns and annealing furnaces, and in many types of indirect-fired heating furnaces.

When it is remembered that a saving in fuel of 30 per cent. can usually be introduced, and that there are other collective advantages of greater monetary value, pulverised fuel firing in metallurgical works will carry a good class of coal and one as free from ash as may be procurable.

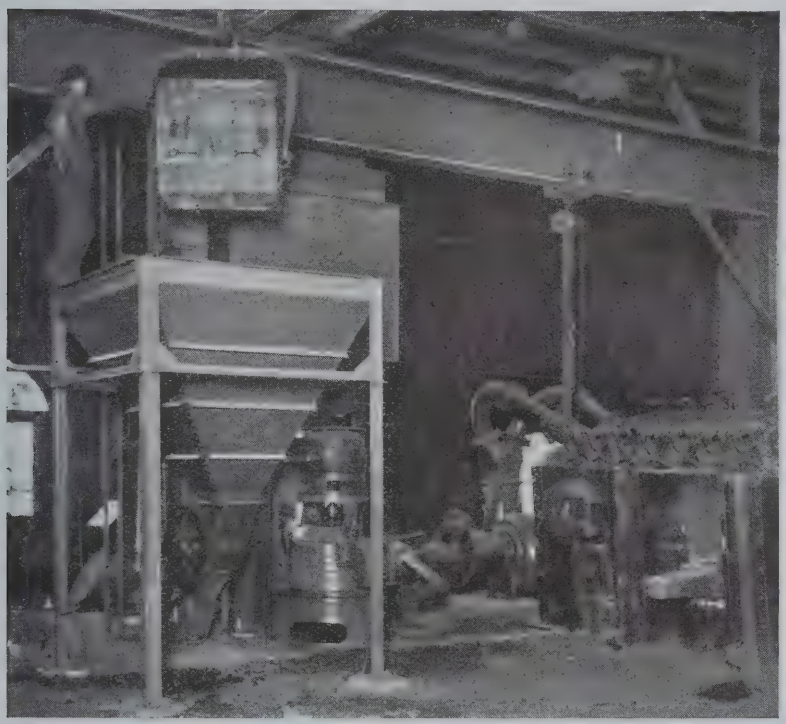
Coal blending in many cases is advantageous, and in the course of time greater use will undoubtedly be made of by-product or residual fuels.

Annealing furnaces.

Many working records are available covering a period of years, and in various countries, which fully confirm the great economies which pulverised coal firing has introduced in the working of reheating furnaces, soaking pits, bushelling and faggoting furnaces, sheet and plate furnaces, heavy and light forge furnaces, press furnaces, and in particular, puddling, malleable iron melting and annealing furnaces. From accurately kept cost sheets at several works an overall saving of 8s. to 10s. per ton of iron melted and annealed has been obtained. The increased life of annealing boxes, in some instances up to double the life previously experienced, is a further valuable consideration. At a works in France the temperature in annealing furnaces can be raised to 700° C. within two hours, thereafter being slowly increased during the next 16 hours to 870° C., and maintained at that temperature for the remainder of the annealing period of 56 hours. The fuel consumption, using slack coal, is 38 per cent. of the weight of charge, the fuel costing 135 frs. per ton as against a cost of 220 to 250 frs. for hand-fired fuel. The overall saving in cost of fuel is 75 per cent. It will be appreciated that annealing conditions are not always the same, as the cycle of operations varies in certain works, but the same proportional economy can be expected in nearly all circumstances.

Malleable iron furnaces.

With regard to the melting of malleable iron, economies are to be looked for not only in fuel saving but in the time which is required for the whole operation from charging the furnaces to the time of tapping. The practice commonly employed is to run two heats from each furnace per day. The first charge, in a cold furnace, naturally shows an increased fuel ratio. The following figures represent average results from a 20-ton melting furnace operated at a works in England. First heat, melting time 15 to 18 minutes per ton of charge, and a fuel ratio of 2.95 tons of metal to one ton of coal burned. On the second heat, the melting time is from 12 to 15 minutes per ton of charge, and the fuel ratio is between 3.22 and 3.28 tons of metal per ton of coal. On the larger 30-ton furnaces the fuel ratio is from 3.57 to 4.0 tons of metal per ton of coal.



Self-contained unit equipment installed on malleable iron melting furnace.

Under previous hand-firing conditions these furnaces produced the same tonnage of metal, but the fuel ratio was between 1.6 and 2.1 tons of metal per ton of coal, also the time element for melting was very variable. Delayed tappings were frequent occurrences, owing to irregularities in firing conditions, which resulted in a corresponding additional cost for moulder's overtime and general works' charges. Since the change has been made to pulverised coal firing, the charging, melting and tapping periods can be regulated to a definite schedule. This, in itself, is of the greatest value in the smooth running of any iron foundry.

Puddling furnaces.

Pulverised fuel firing has also been the means of introducing considerable savings in the making of puddled iron. The normal consumption of fuel for hand-fired puddled iron furnaces is about 3,000 lbs. of coal per ton of muck-bar produced. With similar coal applied in pulverised form, definite records show that fuel consumption, per ton of muck-bar, can be as low as 1,200 lbs. when preheated air is employed. It may safely be taken, therefore, that a saving of 40 per cent. in fuel over hand-fired conditions can be effected and maintained in this type of furnace. In addition, heats are quicker and more uniform. The puddled iron can be worked up with greater speed, so that in many cases one more heat per shift has been obtained; the time for each heat at one works being 2-2$\frac{1}{2}$ hours for hand firing, and 1$\frac{1}{2}$ to 1$\frac{3}{4}$ hours with pulverised fuel.

In regard to blast furnaces, experiments have been made and a reduction in metallurgical coke of ten to twelve per cent. effected by the introduction of pulverised coal with the charge, and as an auxiliary firing medium, but the application has been attended by considerable difficulties at the tuyeres.

Cupolas.

A greater measure of success has been obtained in the use of this fuel as auxiliary firing for cupolas. By this means as much as thirty per cent. of foundry coke can be replaced by pulverised coal. The

respective quantities of fuel used, in relation to the charge of iron, are usually between 1 and 2 per cent. of pulverised coal to 5 or 8 per cent. metallurgical coke. This application of pulverised coal increases the output of a cupola by 25 to 40 per cent. and gives a hotter casting metal. At an iron foundry in France, a small unit installation originally installed for producing " foundry black " has been utilised for augmenting cupola firing with pulverised coal. The cost of the raw coal is 140 frs. per ton, metallurgical coke being 214 to 250 frs. per ton, and the relation of fuel to metal charge is 2 per cent. of coal and 4.5 per cent. of coke. A definite saving in cost of fuel of 11 frs. per ton of iron melted has thus been obtained. The increase in cupola output in this case is 50 per cent. A reducing heat is maintained throughout and sulphur contamination is considerably less than with all-coke firing.

Steel reheating furnaces.

In some instances in Great Britain the self-contained type of unit mill has been installed for metallurgical furnace firing and results obtained compare very closely with those obtained abroad. Unit mills are being used at one steelworks for firing regenerative type reheating and bushelling furnaces. The only change made in the complete furnace structure when adapting it to this form of firing has been to close up the gas producer section and to enlarge the apertures through the regenerative chambers. The operation of the secondary air is retained exactly as for gas firing. The resultant economy is 17 per cent. in favour of the pulverised fuel, with coal costing 14s., as against 23s. for gas firing. It has also been found that the actual value of labour reduction is greater than the saving in the cost of fuel. The reheating of billets and blooms for rail rolling, is effected in Germany with the utilisation of 150 lbs. of brown coal per ton.

A further example of a successful unit mill installation at a British works is that of a general engineering works in the north. A large reheating furnace has been converted from hand firing to pulverised coal firing. The furnace is 35ft. long and is used for heating large plates up to 1½in. thick. It was originally fitted with side grates, but is now fired at the two ends only. It previously took 24 hours to heat the furnace to the required temperature, a period in which from 3 to 4 tons of coal were burned. The furnace can now be heated up in two hours with 25 cwts. of pulverised coal.

For damping down the furnace overnight, between 20 and 30 cwts. of coal were burned under the old conditions. This cost has now been entirely eliminated, and the scaling loss, due to inefficient firing conditions, has been reduced to a negligible figure. Plates are more thoroughly and uniformly heated and require less time and power for pressing. Regulation of temperature at all times is under perfect control, and the dust covering on the plates is readily blown or brushed off before rolling.

In America the use of pulverised fuel at sheet rolling mills is almost standard practice, and the beneficial effect of this method of heating upon the total costs of production is certainly very marked.

Combined oil and coal furnace.

The similarity between powdered coal and oil firing makes it possible to use oil fuel when such may offer special advantage. Burners are now constructed whereby with slight alteration they can be operated with fuel oil or pulverised coal and without any alteration of the combustion chamber. Several installations in America have been erected where both methods of heating are applied, either of which can be put into operation within a few hours' time. The reason for such an arrangement is not only for purposes of standby, but to enable the purchase of the cheapest fuel whether it be oil or coal. Such a condition does not naturally apply in this country because of the abnormally high cost of fuel oil. Burners having this combination are, however, being used in Great Britain with success in the firing of nickel and tin smelting furnaces.

Non-ferrous furnaces.

In non-ferrous blast furnace work pulverised coal has been successfully applied in the production of nickel and copper. In the former case coke consumption has been reduced by 40 per cent. Furnaces for copper have been operated with this system alone, the fuel ratio being 3.8 per cent. of coal in place of 6 per cent. of coke.

The most astonishing economies in non-ferrous operations are evidenced by the present-day general practice of firing open hearth reverberatory copper smelting furnaces with pulverised coal. The furnaces at the Canadian Copper Co.'s works, for instance, after conversion from hand-firing to pulverised coal firing gave approximately double the output at half the fuel consumption. The actual figures are: Hand firing, 250 tons of copper per 24 hours, and 3.8 tons copper per ton of coal; pulverised coal firing, 475 tons of copper per 24 hours and 7.0 tons of copper per ton of coal.

Furnaces for copper reheating and annealing are also in successful operation in England. The coal consumption at one works under hand-firing conditions was 170 lbs. per hour in the smaller furnaces and 400 lbs. per hour in the larger furnaces. The reduction of fuel consumption under pulverised coal firing is 27 per cent. in the former case, and in the latter 28.5 per cent., the fuel used costing 17s. as against 24s. for hand-firing coal.

The evidence of the records available as to the advantages of pulverised coal applications in metallurgical industries is now so extensive that there is little doubt that given the right conditions great economies can be introduced. Apart from the economic fuel aspect, there are advantages such as reduction in metal losses, increased furnace and mill output, accurate control of temperature, a greater degree of heat penetration, making for less wear on rolling mill equipment and machinery, a reduction in the cost of transporting raw fuel, and reduced labour charges due to automatic firing and the changed furnace conditions.

There are, however, still difficulties which have to be overcome in various branches, notably in steel melting. No useful or satisfactory development has, as yet, taken place in this direction.

For most of the other metallurgical firing operations, however, pulverised coal now plays an important role in the general reduction of process costs in competitive countries, and in Great Britain the metallurgical industries are definitely giving this subject greater and more careful consideration.

The obvious applications for pulverised fuel firing are usually those for which a long flame high-grade coal is hand-fired at the furnaces. The cost of such coal at the furnace is usually little short of 30s. per ton, although the position of a works in relation to its coal supplies and market fluctuations will naturally affect this figure. The slack coal from identical seams is of equal heating value when pulverised, and can frequently be delivered at 15s. or 17s. per ton. There are additional costs which are to be reckoned with, consequent upon the utilisation of coal in pulverised form, namely, power for pulverisation, maintenance, overhead charges and transmission of the fuel. The total cost of fuel preparation and burning will lie between 3s. per ton, for large plants, and 10s. per ton for small unit mill applications.

On the basis of a one-third reduction in fuel consumption and taking a conservative total cost of 25s. per ton of pulverised fuel as fired, then 2,000,000 tons of pulverised coal burned will mean a total cost of £2,500,000 as against £4,500,000 for the 3,000,000 tons of hand-fired lump coal.

These suggestions merely touch upon the possibilities of a general reduction of fuel costs throughout the metallurgical industries by the extended use of pulverised coal firing upon the recognised lines of progress made in this direction during the past few years.

PART IV.—THE CARBONISATION OF COAL.

METALLURGICAL COKE.

Chapter 1.

THE ECONOMIC ASPECTS OF METHODS OF COKE MANUFACTURE.

By R. A. Mott, M.Sc.

The total amount of metallurgical coke produced in Great Britain has only varied between approximately 11,000,000 tons and 13,500,000 tons in the years from 1907 (the first year for which statistics are available) to 1925, omitting the two years of extreme trade depression, namely, 1921 and 1922. The average yearly production over this period was about 12,100,000 tons. The allocation of the yearly production is shown in Table I.

The statistics are drawn chiefly from H.M. Chief Inspector's of Mines Annual Reports. Before 1915, separate statistics for coke and coal consumption at blast furnaces were not given; in all years some coal was used directly in the blast furnaces, and the statistics for fuel consumption for the years 1907 to 1914 were recorded as "coal consumption at blast furnaces," the amount of coke being taken as 60 per cent. of the equivalent coal. The same factor has been used to recalculate the "coal consumptions" to coke consumptions, and the average proportion of coal to coke used in the years 1915, 1916 and 1917 was assumed for the earlier years. The figures for exported oven coke for the years before 1921 are obtained by assuming that two-thirds of the total coke exported was oven coke. This assumption is based on the proportion of oven coke to total coke exported in the years 1921 to 1925, and is confirmed generally by the statistics available for the amounts of coke exported from Durham, South Wales, Scottish and Yorkshire ports, in the years 1907 to 1913. (The amount of coke exported recorded is approximately 85 per cent. of the coke exported from these ports.)

It will be observed that until 1918 only relatively small quantities of metallurgical coke were exported, but in subsequent years these quantities were greatly exceeded. Another distinct feature is the increased amount of coke used at home for foundry and other purposes during and after the war.

In recent years, as well as in pre-war years, most of the oven coke production was used for iron smelting in blast furnaces. In the years 1907 to 1913 the average annual pig-iron production was nearly 10,000,000 tons, but in the years 1923 to 1925, the average pig-iron production was only 7,000,000 tons. In spite of the reduced iron production, the average coke production was greater in the post-war years considered, than the average of pre-war years. This indicates that the coke maker is now less dependent on the iron maker than was formerly the case, but a return to the "normal" pig-iron production would greatly increase the demand for coke. The smaller proportion of the total coke production now used for iron smelting is illustrated by the following figures: In the years 1907 to 1913 an average of 87.7 per cent. of the total coke production was used at blast furnaces; during the years 1914 to 1920 the average figure had decreased to 81.6 per cent., and during the years 1921 to 1925 it was only 66.3 per cent.

The amounts of oven coke exported were small during the years 1907 to 1918, but have attained large proportions in post-war years. It must be admitted that this was due to abnormal conditions, the chief of which was the disorganised state of the German coke industry. In the years 1922 to 1925 the average annual amount of coke exported during these four years was 1,855,000 tons, but this included average annual exports of 409,000 tons to Germany, 119,000 tons to Belgium, 117,000 tons to Holland and 94,000 tons to France. These abnormal exports to countries which did not import much coke from Great Britain in pre-war years totalled nearly 740,000 tons. As compared with pre-war figures, the exports to the Scandinavian countries were also increased by an average of 250,000 tons per annum during the same years.

The abnormal conditions which enable this large amount of coke to be exported no longer exist, so that it is impossible to estimate with any exactitude the possible outlet of coke by export, but unless

the conditions have altered considerably, it is possible that the " normal " figure is between 800,000 and 900,000 tons per annum. The chief countries to which coke is normally exported are the Scandinavian countries, Sweden, Denmark and Norway (which together took 455,000 tons of oven coke in 1925), Spain (98,700 tons), and Italy (180,700 tons).

The final column of Table I. is, however, more hopeful in its outlook. Foundry coke is used for the melting of pig-iron, for cast iron, or Bessemer steel manufacture. The Bessemer process for the manufacture of steel is being gradually displaced by the open-hearth process, so that the production of Bessemer steel has decreased from 1,859,300 tons in 1907, and 1,600,700 tons in 1913, to 505,300 tons in 1925, including material made directly from molten iron from blast furnaces. The amount of coke used for iron castings is only small, and it may be estimated that approximately 600,000 tons of foundry cupola coke would be required in 1907 and much smaller quantities in subsequent years.

TABLE I.—ALLOCATION OF METALLURGICAL COKE PRODUCTION.

Year.	Total amount of coke made.	Coke used at Blast Furnaces.	Coke Exported.	Coke used at Foundries and for other Home purposes.
	Tons.	Tons.	Tons.	Tons.
1907	12,322,000	10,982,000	654,000	686,000
1908	11,153,535	9,746,000	795,000	612,535
1909	11,496,551	10,121,000	774,000	601,551
1910	11,925,115	10,652,000	643,000	630,115
1911	11,474,174	9,994,000	707,000	773,174
1912	10,720,352	9,359,000	674,000	687,352
1913	12,798,996	11,036,000	823,000	939,996
1914	11,050,256	9,558,000	789,000	703,256
1915	11,908,940	9,746,743	674,000	1,488,197
1916	13,288,474	10,300,888	988,000	1,999,506
1917	13,555,051	10,961,734	852,000	1,741,317
1918	13,121,311	11,286,680	611,000	1,223,631
1919	11,681,153	9,384,337	1,006,000	1,299,816
1920	12,611,435	10,036,219	902,666	1,672,550
1921	4,573,970	3,075,947	292,648	1,205,375
1922	9,035,741	5,819,084	1,602,671	1,613,986
1923	13,418,314	8,645,700	2,745,905	2,026,709
1924	12,753,358	8,608,890	1,847,762	2,296,796
1925	11,008,686	7,465,600	1,222,476	2,320,610

The marked increase in the quantity of coke recorded under the heading " Coke for foundry and other home purposes " during the war and post-war years, is therefore due to the use of coke for " other purposes." Oven coke is now used for water-heating or steam-raising in central-heating systems, steam road waggons and other boilers, for general heating and drying purposes in foundries (core and mould drying), in bakeries (oven heating), in breweries (malt drying), in greenhouses, and in closed stoves for house heating. The increasing popularity of oven coke for uses outside the iron industries may be attributed to a great extent to the increased manufacture of by-product coke in place of beehive coke, which was too hard and massive for most domestic uses, for which small coke, or easily broken coke, is usually required. The importance of this developing market for oven coke is illustrated by the following figures : in the years 1907 to 1913 an average of 60 per cent. of the total coke manufacture was used for foundry and other home purposes ; in the years 1914 to 1920 this percentage had increased to an

average of 11.6 per cent., and in the years 1921 to 1925 to an average figure of 18.6 per cent., despite the known decrease in the use of coke for foundry cupolas.

Only relatively small quantities of steel are manufactured by the crucible-steel process, but over three tons of coke are used per ton of steel made. The crucible-steel trade is mostly confined to Sheffield, which produced 67,000 tons of special (including " electric ") steel in 1925. Beehive coke only is used in the crucible-steel process.

Production.—The estimated percentage of the total coke production made in beehive ovens, non-recovery retort ovens and by-product ovens is recorded in Table II.

Table II.—Percentage of Coke produced in Beehive, Non-recovery Retort, and By-product Ovens.

Year.	Beehive Ovens.	Non-recovery Ovens.	By-product Ovens.
1900	80	13	7
1907	68	13	19
1912	45	10	45
1914	31	7	62
1918	20	5	75
1924	8	2	90

A summary of the approximate percentages of the total metallurgical coke production made in different districts for a number of years is recorded in Table III.

Table III.—Percentages of Total Coke Production made in Different Districts.

	1905	1908	1913	1917	1923	1924	1925
Durham*	56.5	48.0	45.0	40.5	38.0	37.5	35.5
Yorkshire	19.5	22.0	21.0	26.0	26.0	27.0	29.5
South Wales	7.5	6.5	6.0	5.5	5.0	6.0	7.0
Monmouthshire	5.5	5.0	6.0	7.0	6.5	5.0	4.5
Lancashire	3.0	4.5	4.0	4.5	6.0	6.0	5.0
Staffordshire	1.0	2.5	4.0	4.0	5.0	5.0	4.5
Derbyshire	2.5	5.0	4.5	4.5	5.0	5.5	6.0
Cumberland	1.5	1.5	4.0	4.0	4.0	4.0	4.0
Scotland	3.0	5.0	5.5	4.0	4.5	4.0	4.0
Total Coke production (tons)	†11,000,000	11,153,535	12,798,996	13,555,051	13,418,314	12,753,358	11,008,686

The most noticeable feature of this table is the large decrease in the proportion of the total coke production contributed by the Durham coalfield. The number of by-product ovens in use in Durham, however, has steadily increased, and in the years 1923 and 1924 all the by-product ovens erected were in use, in the former year certainly to their full capacity, so that the decrease in the proportion of coke produced in Durham is due only to the disuse of beehive ovens. The reason why beehive ovens have fallen into disuse may be in part that less pig-iron has been made (for the largest proportion of pig-iron is made on the North-East coast), but it is also due to the fact that the smaller use has been made of Durham beehive coke in other iron-producing districts. Thus, in 1905 only 11 per cent. of the total coke production was made in Lancashire, Staffordshire, Derbyshire, Cumberland and Scotland, but this proportion had increased by 100 per cent. to 22 per cent. in 1913. In the same period the proportions of the total coke production made in Yorkshire, South Wales and Monmouthshire remained substantially

*Including N. Riding of Yorkshire. †Estimated.

constant, and the decreased proportion made in Durham (11.5 per cent.) was balanced by the increased proportion made in the remaining districts.

The proportion of the total coke production contributed by Durham has decreased from 45.0 per cent. in 1913 to 35.5 per cent. in 1925, a decrease which is balanced by the increase in the amount of coke made in Yorkshire from 21.0 per cent. in 1913 to 29.5 per cent. of the total. The proportions of the total production made in the remaining districts were approximately the same in 1925 as in 1913. The further decrease in the percentage of coke made in Durham in this period is due to the displacement of Durham beehive coke by Yorkshire by-product coke in blast-furnace practice.

Coals Used for Coking.—The run-of-mine coal at a pit head passes over screens and the size less than 2in. is usually sent to the washery for cleaning. After washing, the coal is divided into different sizes by screening, and the portion less than $\frac{5}{8}$in. is the material commonly used for the manufacture of metallurgical coke. Such coal may be a mixture of two or more seams worked at a colliery, and may be admixed with the washed slack from other collieries before it is charged to the ovens.

Typical analyses of coking coals are recorded in Table IV.

TABLE IV.—TYPICAL ANALYSES OF COKING COALS.

Coal.	Proximate (air-dried basis).			Ultimate (ash-free-dry basis).				
	Moisture.	Ash.	Vol. Mtr.	C	H	O	N	S
Durham (N.)	0.7	6.3	27.2	87.8	5.0	4.5	1.5	1.2
Do. (N.)	0.9	7.5	27.7	87.3	5.0	5.4	1.4	0.9
Do. (S.W.)	1.1	4.2	29.4	85.8	5.2	6.2	1.6	1.2
Do. (S.W.)	1.2	5.5	24.6	88.7	4.9	4.2	1.4	0.7
South Yorkshire	1.1	6.4	31.4	84.6	5.0	6.5	1.7	2.2
Do.	2.4	7.0	31.5	83.1	5.4	8.5	1.7	1.3
Do.	1.1	7.2	31.0	83.7	5.4	7.2	1.6	2.1
Do.	1.8	6.9	31.7	83.9	5.2	7.4	1.7	1.8
Derbyshire	3.2	6.8	33.8	82.4	5.2	8.4	1.7	2.3
Cumberland	2.6	6.7	33.0	84.8	5.3	6.3	1.6	2.0
Staffordshire	2.6	5.0	33.8	83.4	5.2	8.1	1.6	1.7
Lancashire (i.)	2.0	6.5	20.0	86.1	5.3	6.3	1.8	0.5
Do. (ii.)	2.0	7.2	33.8	81.9	5.2	8.8	1.4	2.7
Scotland	2.0	6.5	30.0	84.7	5.4	7.7	1.5	0.7
Monmouthshire	1.2	6.4	25.6	88.0	4.8	5.1	1.3	0.8
South Wales	0.9	6.7	18.8	89.9	4.4	3.5	1.4	0.8

The ash content of coking coal is usually less than 7 per cent. The volatile matter of South Wales coking coals may be as low as 18 per cent.; in Durham and Monmouthshire it is relatively low, varying from 25 to 30 per cent. In Lancashire, one seam (the Lower Mountain Mine) has a volatile matter content which is sometimes only about 20 per cent., and is the coal chiefly used for making the well-known beehive foundry coke of that county. The other coking coals of Lancashire are of high volatile matter content (over 30 per cent.). The volatile matter content of the coking coals of the other districts is higher than in Durham, being usually from 30 to 35 per cent. The carbon content of many of the South Wales coals are similar to those of many of the low volatile Continental coking coals (namely 88 to 91) and is usually much higher than those of other British coals. Durham coals have the next highest carbon contents which vary between 86 and 89 (on the ash-free, dry, sulphur-free basis). South Yorkshire coking coals have carbon contents varying usually between 84 and 87 (on the same basis). The oxygen content of all coking coals is less than 10 per cent. The nitrogen and sulphur content of Durham, South Wales and Monmouthshire coking coals is frequently less than that of the coking coals of other districts, and the yield of sulphate of ammonia is correspondingly lower, but the resulting coke is of lower sulphur content.

The washed coal through a $\frac{5}{8}$in. screen is drained in hoppers until its moisture is about 10 to 12 per cent., and is then crushed so that 70 to 90 per cent. of it passes through $\frac{1}{8}$in. mesh. The crushed coal is charged to by-product coke ovens either through charging holes at the top of the ovens, or else through a side door after being first compressed into a cake. Compressed charging gives a denser coke than top-charging, and has been held to be essential to obtain a satisfactory coke from poorly-coking coals, but has nevertheless been widely practised with good coking coals. The advantages of compressed charging have recently been called into question. In spite of the less dense coke which results from top charging, it has been found in a number of cases that such coke is more resistant to breakage on dropping than coke made from the same coal in compressed charges. The modern tendency of design in building ovens very much higher and narrower than those previously built makes the use of top charging essential, since a compressed cake with a ratio of height to width of more than about 6 to 1 would break in passing from the compressor to the oven. Moreover, it has already been shown in practice with certain poorly-coking Staffordshire coals, for example, that a better coke is obtained in modern fast-coking Piette ovens from top-charged coal than in an older battery at the same plant in which the coal is charged to the ovens in a compressed state. In America all the ovens are top charged, and it seems likely that this practice will be largely adopted in England in future batteries, even when poorly-coking coals are used. A further disadvantage of the use of a compressor is the time taken to make a cake (about 20 minutes), and

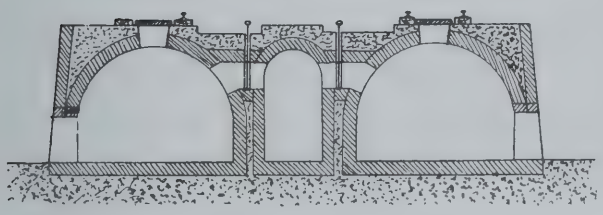


FIG. 1—*Beehive Coke Ovens.*
Sections through ovens and waste heat flue.

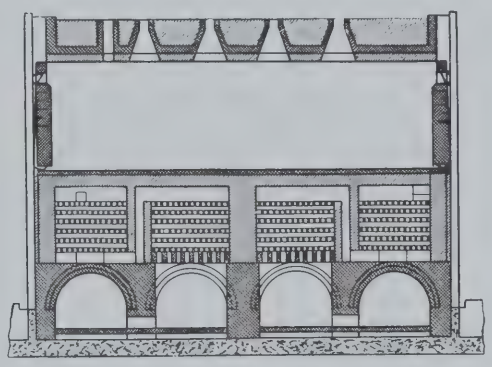


FIG. 2.—*The Semet-Solvay Regenerative Oven.*

the liability of mechanical breakdowns, which make a compressor unsuitable for use under modern fast-coking conditions when a pushing schedule has to be adhered to.

BEEHIVE OVENS.

Before considering the various types of by-product coke ovens it is pertinent to refer to the older beehive coking process. A beehive oven is of beehive or dome shape, about 12ft. in diameter and 7ft. high, built of red brick and lined with siliceous firebrick; the floor may also be made of red brick. The ovens are usually built in double rows, and the gases evolved, after combustion inside the ovens, are discharged into a main waste-heat flue connected to each oven and running longitudinally between the two rows of ovens. Each oven has a damper to disconnect it from the flue when necessary (Fig. 1). The beehive shape allows of repeated heating and cooling without distortion. Each oven is provided with two other openings, one at the top of the oven for charging, and the other at the side remote from the waste-heat flue for discharging. A charge of 4 or 5 tons of fine washed coal is loaded into an oven from tubs running on rails on the top of the ovens, and is raked level by hand from the side. The side opening is then bricked up and luted. In a few hours the heat stored in the oven walls "strikes" through and ignites the gases distilled from the coal. Small openings are made in the two upper corners of the side door and air is drawn in to allow the gas to burn. The temperature gradually increases in the oven due to the combustion of the gas and the dome of the oven is heated to a bright red heat. Heat is radiated on to the coal charge and gradually penetrates through it until coking is complete. The process takes two or three days to complete according to the thickness of the coal charge. When completed, the damper

is dropped, the front door bricks knocked down and the coke is quenched *in situ* by spraying with water. When quenched the coke is drawn with a drag and loaded into waggons.

BY-PRODUCT OVENS.

In by-product ovens sufficient heat is produced by burning from one-third to one-half of the gas obtained, and all the tar, ammonia, benzol and the remainder of the gas is recovered, and because the coke itself is not burnt in the oven, the coke yield is from 5 to 10 per cent. higher than in beehive ovens. For the districts, other than South Wales, Monmouthshire and Durham, the yields of by-products obtained are approximately 30 lbs. of sulphate of ammonia, 3 gallons of crude benzol, and 7 to 9 gallons of tar per ton of coal ; about 10,000 cubic feet of gas per ton of coal is also produced. In South Wales and Monmouthshire the benzol yield is frequently only 2 gallons per ton, and the sulphate of ammonia yield only 20 lbs. per ton, with a correspondingly lower tar yield; the coke yield is, however, much higher than in the other districts. In Durham, the by-product yields are usually intermediate between the examples given. The coals low in volatile matter content yield a gas which is usually of lower calorific value than the gas evolved from coals richer in volatile matter.

The design of the by-product oven has shown great changes during the 75 years of its development, and particularly during the years of the present century, during which the design has been put on a more rational basis. The majority of existing British ovens have an average length of 33ft., a height of 7ft. 6in. to 8ft. 3in., and a width of, about, 20in. A charge of 9 to 10 tons of coal containing 11 per cent. of water is coked in about 32 hours.

The coking industry in Great Britain has reached a critical stage in its development, since over one-third of the total of approximately 10,000 by-product ovens in existence are over 25 years old, over 8,000 are more than 12 years old, and almost all of them may be considered as being old-fashioned, on account of the change of values due to the war and post-war conditions. The increase in the cost of labour, and the decrease in the revenue from sulphate of ammonia, among other factors, have made an increased output per oven per day desirable, in order to meet the increased costs. Ovens of modern design have lengths up to 45ft., heights up to 13ft., and widths varying from 14 to 18in. The charge per oven varies from 8 to 16 tons of coal per oven, which is coked in from 12 to 22 hours, giving a throughput per oven of 16 to 25 tons of coal per oven per day, as compared with the daily throughput per oven of about 6 tons in the older types of British ovens in existence to-day. The best ovens of modern design have therefore three times the coking capacity of an oven which was suitable under pre-war conditions and a smaller number of ovens are required to coke a given quantity of coal per day.

The greater output per oven is due in part to the use of silica bricks, which enables higher flue temperatures to be safely used and in part to the reduction in the width of the oven, which makes a higher rate of heat penetration possible. These modifications enabled the coking time to be reduced, but in order to overcome the reduction in the weight of the charge which may be loaded into an oven, as a result of decreasing its width, it has been necessary to increase the length and height of the oven. This development has been made possible by improvements in oven design, which allow specified quantities of gas and air to be admitted to each heating flue, so that the heat distribution throughout the length of the oven is made uniform. A lack of uniformity of heat distribution with the employment of high temperatures might lead to the local failure of portions of an oven wall. It is therefore of the utmost importance to consider the design of various oven types from the standpoint of the ability to distribute specified quantities of gas and air to each heating flue, and the ease of control of the heating system.

Waste-heat and regenerative ovens.

By-product coke ovens are built with either horizontal or vertical heating flues. Until recently all horizontally-flued ovens were of the waste-heat type, but vertically-flued ovens were built of both the waste-heat and regenerative types. In waste-heat ovens, after recovery of tar, ammonia and benzol, the gas was mostly used for oven heating, and the hot products of combustion at a temperature of 500 to 1,000° C. were passed through a waste-heat boiler installation for steam-raising purposes. From 10 to 30 per

cent. of the total gas production from waste-heat ovens was available for external use such as town's lighting or steam raising. In ovens of the regenerative type, the hot products of combustion were used to preheat air for combustion of the fuel gas in the heating flues, and a smaller quantity of gas was necessary for oven heating.

The modern practice of using higher flue temperature makes it essential to use preheated air, so that in future plants it is probable that the preference will be for the regenerative type of oven. The preference shown in recent years for the regenerative type of oven is illustrated by the fact that, of the 4,400 ovens built in Great Britain up to 1910 over 3,500 were of the waste-heat type, whereas from 1910 to 1920 only about 650 waste-heat ovens were built, compared with about 4,000 regenerative ovens.

Horizontally-flued ovens.

Horizontally-flued waste-heat by-product coke-ovens were the first to be devised for coke manufacture and, under pre-war conditions, they proved their worth for that purpose. They were simple in

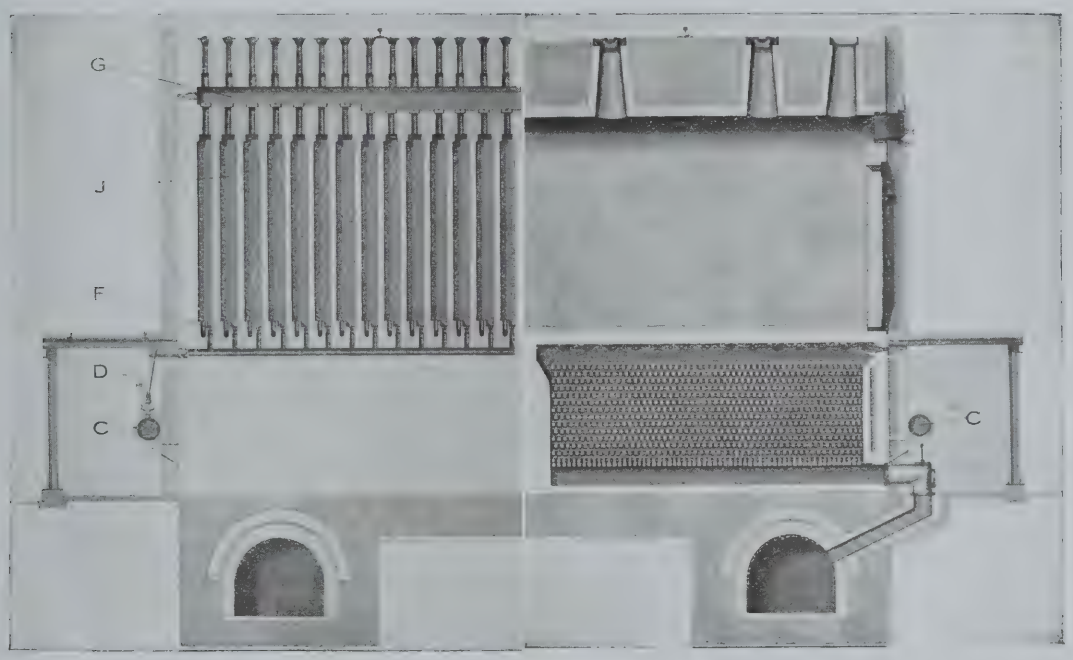


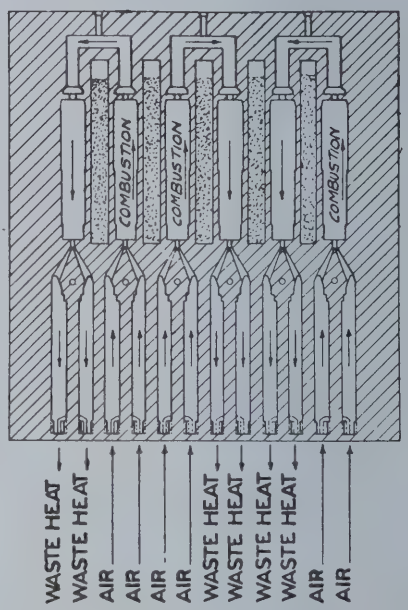
Fig. 3.—*Longitudinal Section through flues and oven of Koppers Taper Oven.*

design and were substantially built. The heating flues could be inspected with ease along their whole length from the sides of the batteries. The coking time of such ovens compared favourably with the coking time of regenerative ovens under similar conditions. The disadvantage of such ovens compared with vertically-flued waste-heat ovens was that the use of horizontal flues did not take advantage of the natural buoyancy of burning gas to draw in the air necessary for combustion, and the draught necessary in the flues was higher than in the vertically-flued waste-heat type of oven. The higher draught used led to greater air leakages, both in the heating flues and in the main waste-heat flue, and therefore reduced the temperature of the hot products of combustion at the steam-raising plant. For steam-raising purposes the vertically-flued oven was superior to the horizontally-flued oven. The higher draught necessary in a horizontally-flued oven also introduced greater danger of loss of gas and by-products by leakage from the oven chamber.

In recent years a regenerative type of horizontally-flued oven has been introduced from America, and the air is supplied to the heating flues under pressure so that it is possible to have a positive pressure

in the heating flues, and the danger of leakage from the oven chamber to the heating flues, is considerably reduced. Since the hot products of combustion are used to preheat the air for oven heating and they are not used for steam-raising purposes, it may be said that the new design of regenerative, horizontally-flued ovens overcomes the disadvantages which existed in the use of horizontal flues in waste-heat types of oven. Modern Semet-Solvay regenerative ovens built in America, are made 35ft. 6in. long, 10ft. 9½in. high, with a mean width of 18½in., to hold a charge of 15 tons of coal, which burns off in about 18 hours, or a daily throughput of 20 tons per day. The design is thus adaptable to give large daily coal throughputs per oven, which compare favourably with any results obtained with modern vertically-flued ovens.

The use of an 18in. division wall between separate ovens increases the ground space of a battery and raises the initial capital cost. The use of silica brick for modern ovens also makes the initial heating up of such ovens a difficult operation, on account of the large volume changes which occur with silica, but once the working temperature has been attained, the large heat capacity of the ovens (approximately, 2½ times that of a modern vertically-flued oven) acts as a valuable heat reservoir, in enforced stop periods of long duration.



COKE-OVEN GAS HEATING

FIG. 4.—*Shewing the flow of air and gas in the Becker Oven.*

A modern type of regenerative Semet-Solvay oven is illustrated in Fig. 2 which shows a longitudinal section through an oven. The heating flues are six horizontal flues on each side of an oven, and are built up of silica "shapes," dovetailed together by rolls and grooves, only four "shapes" being used for the four sides of a flue. The heating flues of adjacent ovens are separated by an 18in. division wall to carry the weight of the superstructure and are built up of standard bricks. Each oven has its own regenerator underneath it and divided into four sections. The regenerators of adjacent ovens are separated by thick division walls which are continuations of the division walls between the ovens. The arch formation of the walls enclosing the transverse section of a regenerator takes the weight of the loaded ovens and the superstructure.

The regenerator is connected near the end of the length of each oven by channels in the division walls to each upper horizontal flue and, also, to the lower horizontal flues. The four sections of a regenerator are supported on transverse arches forming four galleries which serve for waste-gas removal, and for air supply. The arches also take the total load of the ovens. Two adjacent sections of the regenerator, under the half length of an oven, are used to preheat the air for combustion during one period and, on reversal, the other two sections are used for the same purpose.

The use of the large galleries below the regenerators, by ensuring only low maximum gas velocities and therefore small variations of velocity, produces an almost uniform pressure or draught along the whole length of the galleries. This makes the use of individual draught dampers for each oven unnecessary. The amount of air admitted to each vertical air-supply channel is controlled by slides operated from the sides of the battery. The gas supply to each flue is also controlled by the size of the supply orifices in the gas burners at the sides of the battery. There are therefore only two controls used to govern the heating of each oven and both are easily and conveniently operated. This simplicity of control is a good feature of the design. The use of the large sectioned galleries below the regenerators has, however, a disadvantage in that after each reversal the contents of the galleries used for waste-gas removal have all to be transferred to the other two galleries through the regenerator and oven flues, giving a lag in operation, which has an appreciable effect on the nett coking time.

Vertically-flued ovens.

Vertically-flued ovens are built with one set of flues between adjacent ovens. The weight of the loaded oven-charging car operating on the top of a battery has to be carried by the flue walls. The

weakest section of these walls is on either side of the horizontal flue connecting the tops of a whole set of vertical flues. The tendency in modern design is to increase the rate of coking and consequently the quantity of gases passing along each top horizontal flue per unit of time. It is desirable to have only a low maximum gas velocity in this flue, and in order to attain this ideal the size of the flue has either to be increased or other means have to be adopted to reduce the total quantity of gas passing along the flue. The size of the flue cannot be increased beyond a certain point imposed by considerations of structural soundness, and if all the gases from the vertical flues traverse one top horizontal flue a large increase in the rate of coking (throughput per oven) whilst maintaining ideal heating conditions, is not possible.

This principle may be illustrated mathematically, for according to Bernouilli's theorem :—

Total pressure $= ph_1 + vh_1 = ph_2 + vh_2 + Lh$,

where ph_1 and ph_2 = initial and final pressure heads,

vh_1 and vh_2 = initial and final velocity heads.

Lh = loss of head (due to friction, etc.).

This theorem may be stated in the following words : The total pressure of a gas is equal to the sum of its static pressure (pressure head) and its dynamic pressure (velocity head). The losses of pressure due to friction are negligibly small in most oven flues, and if the velocity of travel (and consequently the

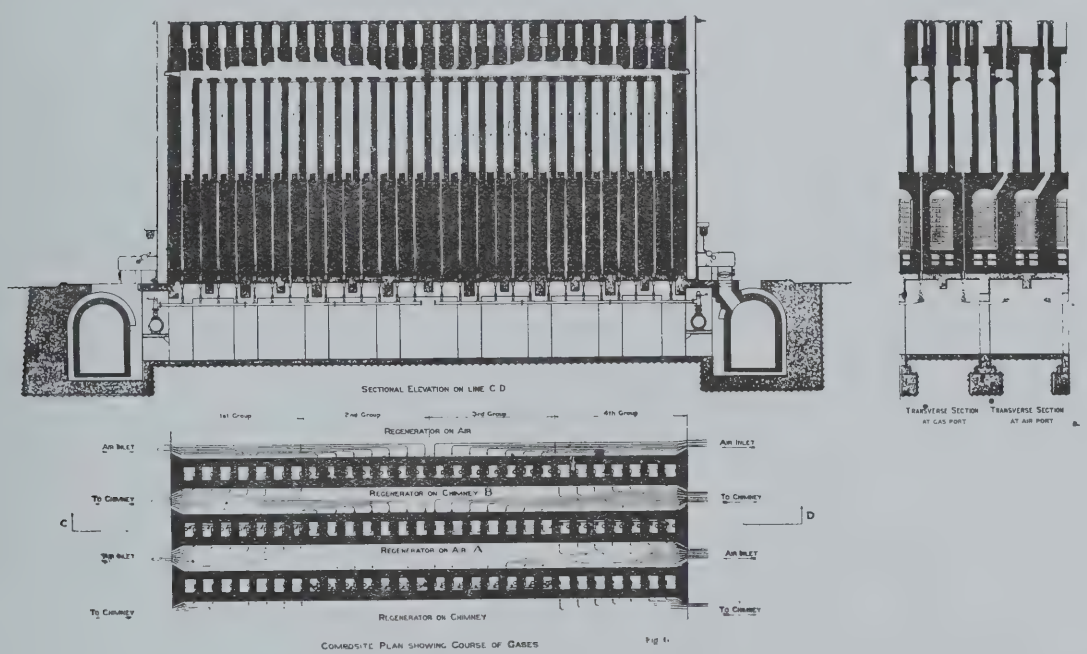


Fig. 5.—*The Simon-Carves Underjet Oven. Longitudinal and Cross Sections.*

velocity head) of the gas be increased, its static pressure will be correspondingly decreased. Conversely, if the velocity of travel of the gas is reduced the pressure head will be increased. The conversion of velocity head (dynamic pressure) to pressure head (static pressure) may be calculated from the formula $v^2 = 2gh$, where v = the velocity, g = the acceleration due to gravity, and h = the pressure head.

In a top horizontal flue of an oven reversing from one half-length of an oven to the other, the greatest gas velocity is attained in the middle of the flue where the gases from all the vertical flues of one half-length of an oven, have to pass. The velocity of the gases is the least at the end of the flue where the gas from only one vertical flue passes. There is a variation of velocity (and consequently of static pressure) along the flue. The distribution of air to each vertical flue from the top of a regenerator depends on the difference in static pressure above and below the vertical flues, and where large differences of static pressure (due to great variations of velocity along the top horizontal flue) occur, air is unevenly

distributed to the various flues. This uneven distribution usually leads to lack of uniformity of heating throughout an oven wall.

The tendency for uneven distribution of air to the various vertical flues may be partly compensated by the use of top dampers at the top of the vertical flues, and adjusted to compensate for the varying pressure or draught along the top horizontal flue. The setting of such dampers is not an easy matter and they may have to be frequently removed to gain access to the vertical flues to clean the gas nozzles. It is therefore preferable to have conditions which cause only small variations of velocity along the top flue.

The closeness to which the designs of various vertically-flued ovens approach this ideal is an important matter in comparing their relative merits.

The Koppers Taper Oven. The Koppers taper oven, illustrated in Fig. 3, owes its name to the vertical taper used in the oven width. The top of the oven chamber is built about 10 per cent. narrower than the base, in order to compensate for the lower temperatures in the upper parts of the heating flues. There are 29 vertical flues disposed in the length of an oven, 15 being supplied by gas from the ram side, and 14 from a gas main, on the wider bench side. Gas is supplied to each section of flues alternately from mains in the two side galleries. From gas main C, a service pipe D, for each oven supplies gas to a gas-distributing channel E, which extends below all the vertical flues of one section and distributes gas to each vertical flue through a nozzle F. Air is supplied through the opening A, in the cast-iron elbows connecting the double channels below each regenerator to the main waste-gas flue. The air is distributed to the regenerator through graduated openings, and passes from the regenerator to the vertical flues through the ports B. Combustion occurs, and the burning gases ascend each vertical flue, uniting in the top horizontal flue G, and descending the vertical flues of the other section they pass to the regenerator and thence to the main waste-gas flue.

The use of a vertical taper for ovens of any width is claimed to increase the oven throughput by from 20 to 25 per cent. The coking time of silica ovens in the battery built at Tinsley Park, Sheffield, which have a vertical taper of 2in. and a mean sole width of 21ins., is 24 hours for a compressed coal charge. But a coking time of 24 hours is used at Whitehaven, Cumberland, for compressed charges containing 12 per cent. of water and over 30 per cent. of volatile matter in 21in. silica ovens without a vertical taper. Since it is known that the use of silica for oven construction enables the coking time to be reduced, the net effect of the taper cannot yet be clearly demonstrated.

The principal claim made for the Koppers taper oven is that it produces coke of "easy combustibility," through heating the charge in an oven uniformly throughout its height (and length), and avoiding overheating of any portion of the charge. To attain this end, the mean width of the oven has been drastically reduced to 14in., and a vertical taper of $1\frac{1}{4}$in. is employed. The oven length is sometimes increased to 36ft. 8in., with a height of 11ft. 2in., to enable a $9\frac{1}{2}$-ton charge, containing 12 per cent. of water, to be coked in about 12 hours. This gives a daily throughput of 19 tons of wet coal. A battery of eight ovens 35ft. 9in. long, 11ft. 8in. high, and $14\frac{5}{8}$in. mean sole width, is in operation at Tinsley Park, Sheffield, where top-charged coal containing 12 per cent. of water is coked in 12 hours.

A disadvantage of this oven when used for fast coking conditions is that a big variation of velocity occurs along the length of the top horizontal flue. This condition, as previously pointed out, makes the uniform distribution of the air to the vertical flues more difficult, particularly if the length of an oven is greatly increased.

The Becker Oven. The Becker oven was designed in America to overcome the difficulties experienced in heating an oven of extended length uniformly. It was also designed to increase the throughput per oven by making use of the known effect of reducing the oven width in increasing the rate of heat penetration in a charge.

An essential difference between the Koppers oven and the Becker oven is the direction of gas flow through the system. In the Koppers oven, the gases from one half-length of an oven pass into a top horizontal flue and traverse it before passing down the flues of the other half-length of the oven. The regenerator, under the length of one oven, is divided transversely at its mid-length, and the gas flow is upward through one half and downward through the other half during the same period. In the Becker

oven, however, gas is burnt over the whole length of an oven, and the products of combustion are collected from the top horizontal flue by, say, six "cross-over" flues over the arch of an oven, to a corresponding top horizontal flue on the other side. From this flue the gases pass downwards over the whole length of the oven. The regenerators are divided longitudinally instead of transversely as in the Koppers oven. To avoid the counterflow of gases as much as possible, four adjacent sections of the regenerators are used for the upstream (air) and the next set of four sections for the downstream (burnt gases). This will be easily followed by reference to Fig. 4. On reversal the direction of gas flow is the reverse of that illustrated in this drawing.

The advantage of the use of cross-over flues is that it reduces the quantity of gas passing along any given point in the top horizontal flue, and therefore reduces variations of velocity and pressure along it. Uniform air distribution to the various vertical flues is therefore facilitated. A further result is that the depth of the top flue is reduced considerably and the structural strength increased. This reduction has several important results. In an older type of oven, reversing from one end of the top flue to the other, the proportion of the height of a charge heated by the gases in this flue is considerable, but since the source of heat is a flameless gas stream of varying velocity along the length of the flue, the heating from this source is less intense than in the vertical flame flues, and is also less uniform. The use of a shallow-top horizontal flue in the Becker oven reduces the proportion of the height of the charge heated by the gases in the top flue, thus enabling a greater proportion of the height of the charge to be heated by the flame flues. The small variations of velocity along the length of the top flue also induces more uniform heating along the length of the upper portion of the oven.

The use of the cross-over flue enabled the height of an oven to be increased from 9ft. 10½in. to 12ft. 6in., or 13ft., and the nett length from 37ft. to 40ft. 8in., while the width of the oven was reduced from 17in. to 14in. A Becker oven permits a throughput of 25 tons of coal per day.

The air distribution to the vertical flues throughout the length of an oven is easily controlled by graduating the size of the openings from the sole flue of the regenerator, and also by using biscuit dampers above reach vertical flue. The simultaneous use of both main waste-gas flues reduces the velocity of the waste gases traversing it and therefore no great variations of velocity occur along these flues. This simplifies the adjustment of individual draught dampers, set to compensate for the varying distances of ovens from the chimney.

The gas is supplied, as in the Koppers oven, from a channel set below the vertical flues. Since this channel is located in a highly heated zone the calculation of the graduation of the orifices below the vertical flues is complicated by the increase in temperature and volume of the gas passing along the channel. This is overcome in practice by fitting removable gas nozzles; in operation the temperatures are determined in each vertical flue by means of an optical pyrometer, and where necessary a different size of orifice is fitted. The position of the nozzles, however, leads to carbon deposition, and this has to be removed by poking from the top of the battery, or by a system of decarboning in which air is drawn or blown through the nozzles.

The sub-division of the top horizontal flue into a number of sections prevents inspection along the flue, but this is not a serious matter since it compels a more rational, if more tedious and difficult, observation of the temperature in each vertical flue.

A disadvantage of the use of cross-over flues lies in the increased heating of the oven arch and higher oven-top temperatures. The cross-over flues are, however, only used over alternate ovens, and the proportion of the length of the oven occupied by the cumulative width of the cross-over flues is only about 8 per cent. of the oven length.

The Willputte Oven. The Willputte oven is similar in general design to the Koppers oven, but the regenerators are sub-divided by transverse walls so that each vertical flue is served by its own section of the regenerator. Air is supplied to the regenerator under pressure from a pipe set below the regenerator, and the waste gas is removed through a separate channel under the same regenerator. Gas is supplied as in the Koppers oven, and the 28 vertical flues are divided into two sections of which that on the ram side includes 15 flues and the section heating the wider bench side, 13 flues. Reversals are made from one section of flues to the other as in the Koppers oven.

Gas distribution to each vertical flue is governed by the size of the orifices used in the gas distributing channel. The same system of standardising these orifices is practised as was described for the Becker oven. The draught is governed by the setting of individual draught dampers for each oven, and by the setting of biscuit dampers at the top of the vertical flues. The openings to the waste gas channel below each regenerator are graduated for a specified distribution of the products of combustion in the down-stream through the flues and the regenerator. The distribution of air is governed by the size of the orifices in the air supply channel, below the regenerators, and by the setting of the vertical flue dampers.

The Willputte oven is one of the longest ovens built which has a simple top horizontal flue of uniform depth. The cross-section of the flue is relatively small. Under the fast coking conditions usually employed very high velocities are attained in this flue and big differences of velocity occur. This does not affect the air distribution, since air is supplied under a relatively high pressure. The large variations of velocity, however, give lack of uniformity of heating throughout the length of the flue, and cause a negative pressure there. In-leakage of air from the sides of the battery and leakage of gas from the oven are therefore more possible.

A battery of Willputte ovens is in operation at Consett, Durham. The ovens are 40ft. long (overall), 10ft. 6in. high, and 17¾in. mean width ; a charge of 13¼ tons of dry coal is coked in 15½ hours.

The Simon-Carves Oven. The Simon-Carves underjet oven is a development of the old Otto oven in which the gas was distributed to the vertical flues from service pipes set in cellars underneath the ovens. The new features introduced are the use of a separate regenerator for each oven, and the separate supply of gas to each vertical flue, but numerous other improvements have also been made in an oven which it may be noted is of British design.

Two types of oven are designed, one in which reversals occur from one half the length of an oven to the other half length, and the other which is illustrated in Fig. 5. This type of oven is in effect two ovens placed end to end and worked in conjunction. For gas distribution, the identity of the two ovens is maintained and the vertical flues are divided into four groups. In any one period gas is supplied to the two outer groups or to the two inner groups. Suitable air distribution is attained by connecting, say, the two outer groups of one set of flues and the two inner groups of an adjacent set of flues to one regenerator. It is thus possible to use the whole of alternate regenerators for air supply and waste gas removal. This may be more clearly seen in the illustration referred to.

Gas distribution to the various vertical flues is made before the gas is heated, and so a specified quantity can be supplied to each flue. This is a special feature of the oven which confers on it greater simplicity and ease of gas control than in the other types considered.

Air is drawn in to a sole flue below the regenerators and is distributed through graduated openings. Biscuit dampers are set at the tops of the vertical flues to compensate for variation of gas velocities, a setting which is aided by the stepping of the flue. Since both main waste-gas flues are used at the same time, and they are built of generous dimensions, the adjustment of the draught on each oven is an easy matter.

The top horizontal flue is designed higher than in earlier types of Otto oven, and is stepped to compensate for the varying quantities of gas carried by different sections throughout the length of the flue. The use of two separate top flues in the total length of an oven, enables the depth of this top flue to be reduced, and the building of much wider flues permits of a further reduction in depth for a given area of cross-section. By these means the disadvantages of the simple top horizontal flue for ovens of large capacity are overcome. In the first place, it enables a greater proportion of the height of the charge to be heated by the flame flues ; secondly, it makes the intensity of heating by the flameless gas stream in the horizontal flue practically uniform throughout the length of the oven ; thirdly, it limits the maximum gas velocity, and so reduces the danger of leakage of air or gas ; and, lastly, it confers a higher structural strength at a zone where the strength is often the least.

The oven can be inspected easily from the sides of the battery and from the top. The gas burners, or pipes, are removable in a moment for adjustment of orifice diameter, or for cleaning purposes. Since it is unnecessary to approach the gas nozzles from the top of the battery, the setting of the vertical flue dampers need never be disturbed when once set. It might be expected that decomposition of gas would

occur in passing up through pipes in the walls of the regenerator, resulting in carbon deposition, but this has not proved to be of consequence in practice. This may be due in part to the vertical travel of the gas which results in less contact with heated surfaces (as compared with horizontal travel), or to slight air in-leakages during the period when gas is not burning in the pipes round the point where the burner pipes enter the lower brickwork, which removes any carbon deposition. In any event, it has not been found necessary to employ a de-carboning device in practice.

The ovens are built on concrete arches which give a stronger and more elastic support than the firebrick walls and arches previously used. The use of separate air ports and draught dampers for each oven puts each oven under separate control, and the setting of the draught damper on one main waste-gas flue for one period of burning, does not interfere with the air supply during the next period of burning, as it did in the old Otto regenerative oven.

The advantage of this new design is that ovens of great length may be built, whilst still conforming to the ideal of uniform heating throughout the length. The height of the oven may also be safely increased. With a length of 42ft. (between doors), a height of 12ft. 6in., and a mean width of 17½in., a charge of 16 tons of coal containing 10 per cent. of water would be burnt off in about 18 hours, giving a wet coal throughput of 21 tons per oven per day. Thus it is well designed to meet the need of large oven throughputs, and the large coal charge used reduces the amount of handling necessary for a given throughput of coal.

The Piette Oven. Another oven of interest is the Piette oven. A battery of Piette regenerative ovens is in operation at Shelton Ironworks of the following dimensions :—Length 36ft., height 9ft. 10in., and mean width, 18in. These ovens are coking top-charged coal containing 13 per cent. of water in 21½ hours. There are 27 vertical flues, divided into two groups of 13 and 14 each, reversals being made from one group to the other. Gas is supplied from the side of the battery through four horizontal feed pipes to four feed compartments, and then through the gas nozzles to the vertical flues.

For each group of flues two regenerators are used and are set transverse to the length of the ovens, and are continuous along the whole length of the battery. Air is drawn by a fan along channels, set above and below the regenerators, to the free space above the smaller "secondary" regenerator. The air is preheated in passing in series through this and the larger "primary" regenerator, and is distributed from the sole flue through graduated ports to the vertical flues. The products of combustion after traversing the top horizontal flue pass down the other group of flues to the other sole flue, and thence through the other primary and secondary regenerator to the free space above the latter, which is used as a main waste-gas flue in this period.

Variations of velocity along the top horizontal flue, are compensated by the permanent graduation of the discharge orifices of the vertical flues. The control of the gas distribution to each group of flues is an empirical operation, which would be difficult to adjust exactly for an oven of great length. The use of a sole flue of large dimensions, in which only low maximum velocities are attained, simplifies the problem of specified distribution of air to the vertical flues. The air is admitted to the sole flue at about half its length, but the air ports are graduated to give the smallest apertures at the centre of the oven, at which point in the sole flue the static pressures would be the lowest. Since the regenerators are not sub-divided, there will be some difficulty in admitting the same amount of air for each oven of a battery. It is the practice with these ovens to use an excess of air in the up-stream of gases, and to admit about 25 per cent. of the total amount of fuel gas to one section of the top horizontal flue, so that further combustion occurs in the down-stream. The use of the free space above the chequer work of the smaller regenerator both for main waste-gas removal and for air supply has a disadvantage in introducing a lag in oven heating on reversal; moreover, the collection of the coolest waste gas (which being heavier naturally tends to fall) at the top of the regenerator space increases the draught necessary for waste-gas removal.

This brief description of the principal types of oven which are of interest to British coke makers, should suffice to indicate the superiority of ovens of modern design over most of those which are at present in operation but which were designed to meet conditions now existing no longer.

Chapter 2.

BLENDING AND PREHEATING COALS.

By John Roberts, D.I.C.

It is becoming generally recognised that an important part of the process of coal carbonisation consists in the preparation of the coal before it is charged into retorts. In former years too little attention was paid to this operation, and the coke maker as a rule restricted his selection of coals to those well known to possess good coke-making or gas-making properties. Nowadays, however, carbonisers realise that in most cases the coal as mined, or as it leaves the coal-cleaning plant, is not in the best condition for coking, and as the result of a fairly exhaustive series of researches by several workers the range of coals available for treatment has been extended to include every class of coal, from sub-bituminous to anthracite.

The coals with which we are concerned may, for our purpose, be classified as in Table I., in which all figures are percentages.

Genus.	Volatile content.	Fixed carbon.	Oxygen and N.	Character of carbonised residue.	Group and class.
Sub-bituminous.	40—55	55—60	15—20	Non-coherent.	(1) High-volatile non-coking.
Bituminous.	32—40	60—68	10—14	Open porous coke.	(2) High-volatile coking.
	26—32	68—74	5.5—11	Porous hard coke.	(3) Normal coking coals.
	18—26	74—82	5.5—6.5	Very dense coke.	(4) Low-volatile coking.
Semi-bituminous.	15—20	80—85	4—4.5	Non-swelling or non-coherent.	(5) Steam coals.
Anthracitic.	8—15	85—92	2—4.5	Non-coherent.	(6) Smokeless steam coals.
Anthracite.	Below 8	Above 92		Non-coherent.	(7) Anthracite.

It will be observed that Group 1 in the table embraces coals of high volatile and high oxygen content. The residues obtained on heating at 900° C. are non-coherent, that is to say these coals will not yield coke when carbonised without the aid of a binding ingredient. Many attempts have been made to convert such coals into coke, chiefly by means of the addition of agglutinants such as pitch, starchy substances, sulphite residues, etc., but these expedients have not been successful, except on a small scale. The coals have been utilised to a certain extent in coking, mixed with coking coals, but it is safe to say that their use in this direction has been more fortuitous than systematic or scientific. The yield of gas and tar with these coals is high, but the gas gives a higher proportion of inerts than is the case with the best coking coals.

Group 2 in the table includes some coals which have feebly-coking qualities, as well as coals which swell considerably during carbonisation. In general, the coke produced is of an open porous texture, and good coke can be produced from such coals only when steps are taken to repress the excessive development of cell structure. The gas yield is high, and somewhat richer than that of coals of Group 1.

The coals of Group 3 embrace the best coking coals such as those of Durham, South Wales, and South Yorkshire. The cokes produced are generally dense and hard, but possess the necessary cell structure to ensure

good combustibility in blast furnaces and cupolas. The best of these coals have volatile contents in the region of 26-28 per cent. The gas yield is large and rich in quality.

Coals of this group expand on heating, and they are often spoken of as strongly-swelling coals. This feature is due to the presence in the coals, or to the formation during carbonisation, of an excess of binding material —more than is necessary to form coherent coke. This must not be taken to mean that the coals contain too much binder for the formation of good coke as they yield an excellent product ; rather it should be understood that the surplus binding properties may be reduced, or otherwise utilised, without detriment to the production of satisfactory coke.

As a rule, coals of Group 4 yield cokes of a denser texture than do the normal coking coals, and expand less during carbonisation, but in this, as in other cases, some exceptions will be found. The gas contains a relatively small proportion of inerts, but the total yield is less than with the coals already described. Coals approaching 18 per cent. volatile are in demand as steam coals.

Group 5 embraces low-volatile steam coals which are mostly coking. The cokes produced are very dense in texture and non-swelling. As the lower volatile limit of 15 is approached, the coals become either feebly-coking or non-coking. Their normal use is for steam raising.

Groups 6 and 7 include anthracitic coals and anthracites having very low volatile and oxygen contents, and yielding non-coherent residues on carbonisation. On account of the low volatile yield of these coals their use in carbonisation has been very limited in the past, and in low-temperature processes it would at first sight appear to be hardly worth while passing them through a carbonising system, since the yield of gas is almost negligible, below 600° C. Factors other than volatile yield however, have to be taken into account, and it will be shown in the sequel that there are cases where it will be advantageous to make use of the slacks of such coals, as well as those of steam coals generally.

PREHEATING.

The coke now made from superior coking coals in by-product coke ovens satisfies the requirements of iron and steel manufacturers, and the object of this discussion is not necessarily to improve the quality of, say, Durham coke, but to suggest the wider adoption of improvements in methods of manufacture, and the better utilisation of available coal supplies. Coke makers naturally have hitherto concentrated on the use of the best coals for their purpose, with the result that coal of doubtful coking quality has found a limited market, and much of it has been left unmined during the exploitation of the mines, while the richer coals have been ruthlessly attacked, and as ruthlessly used. Our resources of coal are limited, and our supply of good coking coals much more so, hence it is desirable from the national standpoint that every effort should be made to make the best use of coals of all classes. This consideration, however, would not carry much weight unless it could also be shown that some tangible and immediate economic advantage would result. This is what we essay to do in these notes, taking as our postulate that the maximum advantage in coking processes generally, is obtained only when the condition of the charge undergoing carbonisation is such that sufficient, but no excess, binder is present.

A study of the mode of formation of coals and of the behaviour of the coals classified in Table I. reveals the fact that, at some stage during their formation, sub-bituminous coals become converted into coking coals, and in what may for convenience be termed the third stage (Class 3), the binding ingredient reaches a maximum, and at the same time a considerable amount of volatile matter, consisting chiefly of inert gases, is eliminated. As the process of the secular degradation of the coal substance proceeds, a further loss of volatile content is brought about, and a decrease of binder, or a lowering of the coking index of the coals. The author has shown elsewhere that this is due to a natural process of heat treatment or carbonisation. This suggests that the coking properties of coals can be modified by heat treatment if desirable, for the purpose of reducing the coking index as a preliminary to coking.

Although excellent coke can be made from a coal of high coking index, there are certain disadvantages attending the use of such coals in the unprepared state, and it is not absolutely essential that coals of maximum coking index should be used. The chief disadvantage of using strongly-coking coal is the fact that the decomposition of the surplus binder is accompanied by the development of excessive cell structure, and the swelling of the charge. This results in the retardation of the coking process, because the plastic layer which is formed during

this stage is a formidable bar to heat penetration. Coals which naturally contain only just enough binder to form sound coke carbonise more rapidly than do strongly-coking coals, so that if the proportion of binder is reduced in the latter, improved heat penetration and increased speed of coking will be brought about.

There are four ways in which this object may be attained: (1) Preheating the coal at temperatures below 300° C. in the presence of air; (2) preheating at the same temperature in the absence of oxidising agents; (3) preheating and partially distilling the coal at temperatures below 500° C. in the absence of air; and (4) utilising the surplus binder by mixing strongly-coking coals with inert fuels, such as anthracite, semi-anthracite, coke dust, or high-oxygen non-coking coals. These processes will be dealt with in the above order.

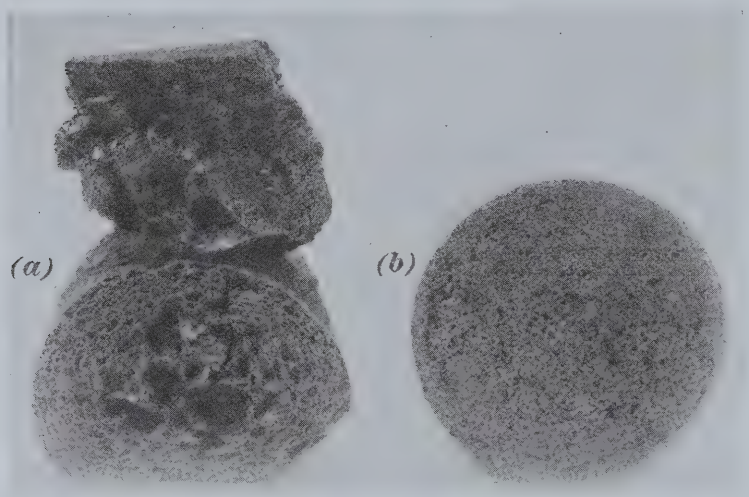


FIG. 1.

Preheating processes were originally proposed to overcome the difficulties experienced in the manufacture of smokeless fuel under low-temperature conditions. The author proposed in 1920 to preheat coals in the presence of air at temperatures ranging from 100° to 300° C., as it was found that coals which gave trouble in low-temperature plant through swelling and sticking could be easily worked if the binder was first reduced in this manner.

Moreover, the semi-coke produced was firm, even-textured, and of superior quality generally, and it was found that the coking operation was performed in appreciably shorter time than when untreated coal was used. The photographs reproduced in Fig. 1 show the effect of preheating on a coal which normally develops a spongy structure (*a*), but which, on carbonising after oxidising at 150° C. to reduce the binder, gives a uniform non-swelling coke (*b*).

In this system it was prescribed that the coal should first be crushed to pass a 1/10-inch mesh, and then heated in a current of air for a period of about one hour. The coal was then to be passed into a coking chamber, and carbonised at any required temperature.

The system has since been revived by Clarence B. Wisner, and forms the basis of the Carbocite Dual Coal Carbonisation system, which is to be exploited at Canton, Ohio, for the manufacture of smokeless fuel. Wisner also has found that the system offers advantages in coke manufacture, in that equally as good coke can be obtained from a given coal whilst effecting a saving of one-third of the coking time, by first oxidising the coal in a rotary retort and then coking at high temperature in coke ovens.

The reduction in coking time can be readily understood when it is remembered that, not only is the plastic layer entirely eliminated, but that the water driven off from the coal—both hygroscopic moisture and water of constitution—is carried away at a temperature not exceeding 300° C., whereas in the regular coking system the water is unnecessarily superheated to the carbonising temperature. This water is thus needlessly passed through the condensing system. The higher the coking temperature the greater the economy of heat in proportion which results from preheating.

In the Parr and Layng system a temperature not exceeding 300° C. is employed in the preheating process, but it differs from the oxidising process in that air is excluded from the preheating chamber. The raw coal is preheated in a rotary kiln by direct contact with non-oxidising hot gases, and is subsequently carbonised in vertical retorts. The waste gas from the flues surrounding the retorts is used for internally heating the kiln. The temperature employed in the first stage is about 25° or 50° C. below the temperature at which the coal becomes pasty, and the duration of treatment in this conditioning stage varies from $\frac{1}{4}$ hour to 2 hours. The temperature in the second stage reaches 750° C., and the preheated coal is charged into vertical retorts while hot.

In this process, as well as in the oxidising process, advantage is taken of the exothermic reactions which occur in the carbonising stage at temperatures between: (*a*) 350-400°, and (*b*) 400-500° C., the latter being the more important range with high-oxygen coals. These exothermic reactions tend towards autogenous carbonisation. In the fractional coking processes (system 3), the reactions referred to are interrupted, as the preheating is carried out at a higher temperature than 300° C.

In the preceding processes the loss of volatile in the first stage is very low, and consists chiefly of moisture and inert gases which it is advantageous to remove early. In the fractional coking system a considerable portion of the volatile matter is evolved during the preheating, which takes place above the initial temperature of decomposition of the coal. Parr and Olin, in 1912, suggested that coal might be carbonised in two stages: first converting part of the coal into semi-coke, and then mixing crushed semi-coke with raw coal, and carbonising at low temperature for the production of a dense smokeless fuel.

The Carbocoal process, invented by C. H. Smith in 1915, may also be regarded as a fractional coking system, but instead of blending the product of the first stage with fresh raw coal, he subjects the whole charge to partial distillation, in order to reduce the volatile and moisture contents. The preheating temperature he employed was 440° to 650° C. In this manner the binder was so reduced in the primary stage that an even-textured, non-swelling coke was produced in the secondary stage.

Charpy and Godchot, in 1918, also proposed subjecting a coal, too rich in volatile matter, to partial distillation at 450° C., and then coking at 700° C.

Illingworth, in 1920, suggested preheating coals at temperatures not exceeding 500° C., in order to reduce the proportion of " resinic matter " to about 5 per cent., which meant leaving sufficient binder in the preheated coal so that it would yield coke in the second stage, as in the Carbocoal process. Carbonisation in the second stage of Illingworth's process could be carried out at temperatures up to 1,000° C.

The McEwen-Runge Process system also embraces preheating, but as a preliminary to the carbonisation of coal for the production of powdered smokeless fuel. The process is carried out in two stages, the dust being first preheated in a vertical retort at a temperature of about 300° C. The inert gases and steam driven off in this stage are allowed to pass away into the atmosphere. The preheated coal is then passed into a secondary retort and carbonised at about 550° C., the volatiles evolved being passed through the recovery system. The heating medium in the preheating stage consists of spent gases after heating the secondary retort.

Advantages and disadvantages of preheating.

Since it is possible, in preheating processes, to control the behaviour of the binder of strongly-coking coals, these systems facilitate the manufacture of semi-coke to a remarkable degree, and an improved product results. In high-temperature practice also, preheating may in some cases be employed to advantage. Although a certain amount of heat energy is required in the first stage, this generally means the utilisation of waste heat from the second stage, and there is usually available on a carbonising works sufficient waste heat to effect the conditioning process. The important advantage of eliminating moisture and inert gases in the preliminary stage is also present.

It has been noted that Parr and Olin showed that a somewhat similar product could be obtained by blending semi-coke with virgin coal. Now semi-coke behaves much in the same way in blending as does a natural inert fuel, such as a high-oxygen non-coking coal, hence it is not absolutely essential to destroy, or partially destroy, the coking properties of a coal for this purpose, except where coking coals only are available, and as a large proportion of British coals are non-coking, it would appear preferable, in the majority of cases, to conserve coking coals by utilising the binder contained in them to bind inert material of coals which normally do not yield coke. This is accomplished by blending.

BLENDING.

Although there are many cases where it will be found advisable and economically practicable to modify coals by preheating, blending systems will undoubtedly make a stronger appeal to coke manufacturers. They have also a wider application, in spite of the fact that blending *per se* does not offer the advantages accruing from the elimination of moisture, etc., as in preheating systems. The main object in blending, as in the processes

already outlined, is to ensure that the charge to be carbonised contains no more binder than is necessary for the formation of coke or semi-coke of the requisite quality. The second object, which is also very important, is to make use of the slacks of coals which are not normally used for coke making, thus preparing these fuels in a form suitable for the domestic and industrial markets. The inert fuels to be considered in this connection are anthracite, semi-anthracite and smokeless steam slacks, coke breeze, and high-oxygen non-coking and feebly-coking coals.

Considerable attention has been devoted to the problem of utilising anthracitic fines. The chief methods employed up to the present being briquetting with the aid of pitch binders, an important industry having developed on these lines. Recently a smokeless binder has been successfully substituted for pitch for this

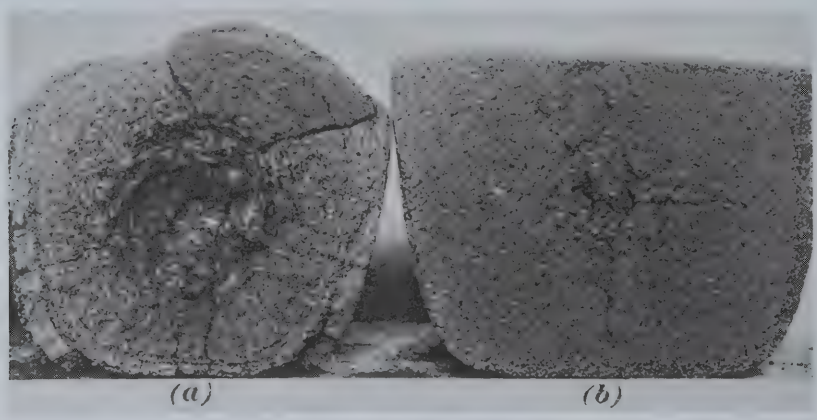


Fig. 2.

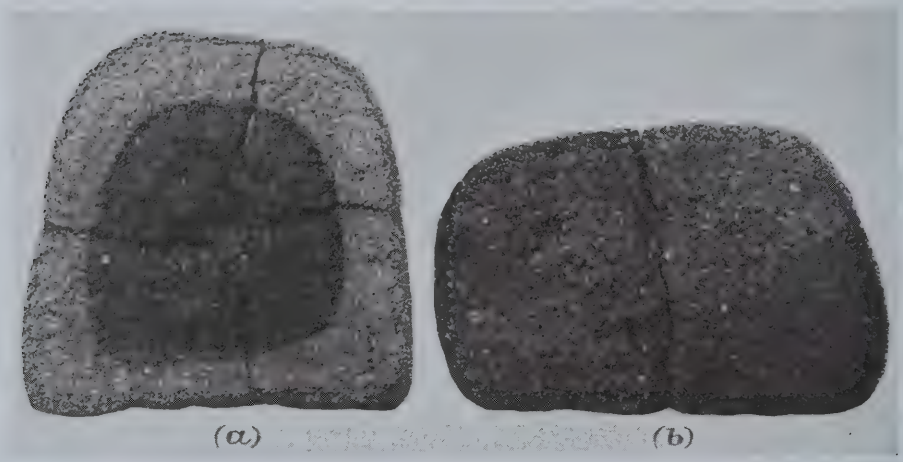


Fig. 3.

purpose. The cost of pitch, however, has frequently hampered the industry, hence it is advisable to explore other avenues which would offer a means of using up anthracitic coals, blending being one solution to the problem.

In considering whether low-volatile coals and anthracites should be used as inerts in blending, the question of the yield of volatile therms must be taken into account. Here it must be remembered that physically and chemically anthracite behaves in every way as if it had been naturally carbonised at a temperature of about 500° C., under great pressure in the earth's crust. Therefore, it must not be expected to yield volatiles when subsequently distilled at that temperature, so that in low-temperature processes and in gas manufacture a low yield of volatile therms will be produced, and a high yield of semi-coke or coke. On the other hand, if the surplus

gas of the carbonisation process does not find a ready and profitable outlet, there is not much point in producing large yields of gas so long as high yields of the solid fuel are obtained at an economic rate. In certain circumstances, therefore, it will be found advantageous to use anthracite as the inert " blotter " with strongly-coking coals, where the anthracite can be obtained at a price which would justify putting it through a carbonising system.

In low-temperature processes not exceeding 500° C., the use of anthracite as the inert would be equivalent to the use of coke dust, since neither would yield volatiles at that temperature, but the semi-coke from the anthracite blend would not be so tough as that from the coal/coke blend. This is due to the fact that coke particles are porous, and allow the binder to permeate through the mass, whereas anthracite is non-porous and the binder merely attaches itself to the surface of the particles.

The foregoing remarks relating to anthracite apply with almost equal force to the use of low-volatile steam coal slacks. In high-temperature coking both classes of coals may be used, and the steam slacks have commonly been employed at plants in South Wales for several years. This accounts for the relatively low yield of by-products from Welsh coking plants as compared with, say, Yorkshire plants. In the former the average yield of benzol (where recovered) is from 1 to 1½ gallons per ton; tar, 56-58 lbs.; sulphate of ammonia, 18-20 lbs.; and gas, 8,000-10,000 cubic feet. In Yorkshire the corresponding yields are: benzol, 2½-3 gallons per ton; tar, 112 lbs.; sulphate of ammonia, 22-35 lbs.; gas, 10,000-11,500 cubic feet per ton. The yield of coke in South Wales, however, is about 75 per cent., as against about 66 per cent. in Yorkshire. These yields have to be borne in mind in deciding as to whether the use of low-volatile inerts is likely to be a profitable proposition on a given plant.

Blending with coke dust.

An excellent absorbent for the surplus binder of rich coking coals is coke breeze. The chief advantages arise from: Its use in suitable proportions increases the toughness and crushing strength of coal; it eliminates the plastic layer, prevents expansion of the charge, and facilitates the transmission of heat during carbonisation. Coals which yield cokes of extreme density can be suitably " opened up," to give the required cell structure to ensure good combustibility, while coals which yield spongy coke can be made to produce coke of smaller cell structure and denser texture. The size of material used will depend on specific requirements. As a rule the coke breeze should be sufficiently fine to pass a 1/10-inch mesh, but larger sized material may be used if the normal coke is particularly dense. The objection to its use is the high percentage of ash which it generally carries, but it will be appreciated that if the whole of one's own make of breeze is returned to the retorts, the resulting coke should not contain more than the " theoretical " yield of ash.

It has at times been urged that the use of breeze diminishes the real throughput of a retort, but the contrary has been found to be true in practice, the enhanced rate of coking more than counter-balancing the loss of capacity of the retort as a result of the introduction of breeze into the charge. In other words, the throughput of raw coal will be increased even though the charge may contain 25 per cent. of material which has to pass through the process a second time.

The effect of the addition of breeze is illustrated in Fig. 2, in which (*a*) is the coke from a Welsh coking coal, while (*b*) is a coke from the same coal suitably blended with coke dust.

The supply of coke breeze and anthracite is limited, so that if blending is to become general another class of inert fuel must be used. Fortunately, the most suitable is also the most plentiful, namely, high-volatile non-coking or feebly-coking coals, and these coals offer other advantages over such fuels as anthracite and coke dust. Firstly, the yield of gas and other by-products is high, and the revenue to be expected from this source is appreciable. Secondly, the exothermic reactions of high-oxygen coals undergoing carbonisation contribute materially to the conservation of heat in the process.

On the other hand, it must be noted that the gases evolved from these coals are not so rich as those given off from the normal coking coals, as high-oxygen coals evolve comparatively large quantities of CO_2 and water of constitution. For this reason, it would be anticipated that the mixing of a high-oxygen coal with, say, Durham coal would result in the production of gas of lower calorific value. There are, however, two factors which tend to counter-balance this. In the first place, the yield of water of combination will depend on the rate of heating. Rapid heating may reduce the amount of water evolved by one-half, as compared with slow heating. As the use

of the inert coal would eliminate the plastic layer, a more rapid rate of heating would be accomplished in the case of the blend than with the " straight " coal.

Further, high-oxygen coals are strongly exothermic at temperatures between 300° and 450° C., more so than coals of lower oxygen content, hence the former aid the carbonisation process to a greater extent than do the latter, thus increasing the speed of carbonisation. Consequently, the enhanced rate of heat penetration resulting from the use of a high-oxygen coal would tend to reduce the yield of water in carbonisation, and offset to some extent the high inert content of the gaseous products. It has been found in practice that, although a lower yield of volatile therms per ton of coal carbonised is obtained, a higher yield of volatile therms and of coke per day *per retort* can be secured with high-volatile non-coking coal than with an unblended normal coking coal.

The characteristic effect produced when high-oxygen inert coal is used, and the blend is carbonised at about 750° C., is shown in Fig. 3, in which (*a*) is the coke obtained from the blend, and (*b*) that of an ordinary black semi-coke, shown for contrast. It will be seen that specimen (*a*) is surrounded by a bright layer of coke which possesses some of the characteristics of metallurgical coke. This layer is very hard, has a metallic " ring," and usually breaks with a slaggy fracture. The inner mass is black and has the lustre of ordinary semi-coke. A coke similar to that described may be made under either high- or medium-temperature conditions, and would form a suitable domestic smokeless fuel containing 5 to 8 per cent. of volatile matter. It is free-burning, non-spongy, and its ability to stand transport would be accepted without question. The method suggested for its manufacture is dealt with in the chapter on Blending in Gasworks Practice, and this is, perhaps, where blending offers the greatest possibilities.

The effects described in the preceding paragraph may also be produced by the substitution of an artificially prepared non-coking coal for the natural non-coking coal. In this process, proposed by the writer, a coking coal is first oxidised at temperatures below 300° C., until the coking properties are destroyed, or partially so. The preheated coal is then mixed with good coking coal in suitable proportions, and carbonised at any desired temperature. This system is a modification of the oxidising process which may be employed in cases where suitable inert coals are not available for blending.

Another important advantage to be derived from blending in coke ovens is the fact that coals which formerly required stamping, or compressing, in order to produce satisfactory coke, can be made to yield excellent furnace coke by blending semi-coke fines with the normal coking coal. This plan has been adopted on certain plants in Silesia and Westphalia, with the result that, in the former province, coke makers do not now require to import superior coking coals from outside sources, and in the latter province stamping has been abolished on plants where such blending has been adopted.

Recapitulation.

From what has been said, the advantages of blending will be apparent. Any suitable inert carbonaceous material may be used for this purpose, but the choice will naturally fall on the material nearest to hand, and the cheapest. Anthracite duff and breeze may be used where they can be obtained at low prices, but these inerts contain little or no volatile matter, and cannot be expected to yield by-products. High-volatile non-coking coals, however, are comparatively cheap and plentiful in some fields, and possess the advantages of giving off by-products, and at the same time yielding a superior semi-coke when carbonised at medium temperature. In most cases, therefore, the choice of inert blending material would fall on such lignitous, non-coking coal.

Some feebly-coking coals will not bind inerts, and should therefore be carbonised direct, inasmuch as they do not expand on heating. The strongly-coking coals, especially those having a volatile content above 20 per cent., are very suitable for blending with non-coking coals of volatile content ranging between 20 and 45 per cent. Coals like the Parkgate and Silkstone seams give excellent results with about equal weights of non-coking coal. Other coals would work well with from 10 to 30 per cent. of non-coking coal, but some very strongly-coking Kent coals will successfully bind about twice or three times their weight of non-coking coals.

Incidentally, it may be mentioned that Kent coals which are known to play havoc with gas retorts may also be satisfactorily worked if preheated and oxidised at about 230° C., for an hour or so.

The proper proportions for any given coals can, of course, be readily determined by a few trials in the laboratory. Anomalous results, however, are sometimes obtained with certain coals. For example, mixtures

of the 2ft. 9in. seam from Maesteg, with 10 and 14 per cent. of breeze gave good dense cokes; coke produced from 80 per cent. of coal and 20 per cent. of breeze was very spongy, while very good dense coke resulted with 30 per cent. of breeze. Similarly, it has been observed on trials with 50-lb. charges of certain coking and non-coking coals, that a 60/40 mixture would give a good coke, a 50/50 mixture was unsatisfactory, and a 40/60 blend gave a desirable coke. Such cases, however, are comparatively rare, the general rule being that the addition of inerts improves the quality of the product up to a point, and any further addition of inert would result in an inferior coke.

The temperature of carbonisation must also be borne in mind in determining the state of the blend. Some feebly-coking coals will coke only at high temperature where the temperature gradient is steep. A coking coal may be oxidised to such an extent that it will not coke at 750° C., but if placed in a furnace at 1,200° or 1,300° C. it will yield a dense coke. In like manner, a coking coal may, with advantage, stand 10 or 15 per cent. of breeze at high temperature, but the addition of breeze would be a disadvantage if carbonisation were carried out at 600° C. Due to the low-temperature gradient in the latter case, a large proportion of the coal would remain at a temperature of from 100° to 300° C. for a considerable period, with the result that the binding constituent would become oxidised, and would subsequently fail to exercise its function as a binder. Efficient blending and rapid heating go hand in hand.

SUMMARY.

1. Large quantities of inferior products, such as anthracite duff, coke breeze, and non-coking slack, which have hitherto been prodigiously wasted, are available for blending with coking coals for carbonisation at high, medium, or low temperatures.

2. The blending of inert material with good coking coal generally results in improved coke, prevents expansion of coal during carbonisation, and facilitates heat penetration in the charge.

3. Mixtures of non-coking coal, having a volatile content of upwards of 20 per cent., with good coking coal, are pre-eminently suitable for carbonisation at temperatures ranging from 600° to 760° C., yielding a readily-ignitable semi-coke of comparatively great crushing strength and capable of standing transport with the minimum production of fines.

4. The effect produced in (3) can also be obtained by the use of an artificial non-coking coal, that is, a coking coal, the coking properties of which have been destroyed by oxidation or by a preliminary heat treatment.

5. The addition of inert matter to charges of coal restricts the formation of a non-conducting plastic layer, and tends to increase the rate of gas evolution during distillation.

Chapter 3.

BY-PRODUCTS FROM THE MANUFACTURE OF COKE FOR METALLURGICAL USE.

By J. Macleod, F.I.C., M.I.Chem.E.

Following the introduction of externally-heated coke ovens by Coppee in 1861, attempts were made to recover some of the marketable constituents of the crude gas produced, and twenty years later a distinct by-product coking plant was established.

Modern commerce demands supplies of coal tar and its derivatives, and with markets thus assured the producers of metallurgical coke can pay greater attention to the recovery of the by-products. Especially is this the case where a near-by town can take a supply of the surplus gas.

The recovery of the liquid by-products tends to facilitate the economical production of coke of uniform quality and thus the benefit is general.

Magnitude of the coking industry.

There are about 130 undertakings in the country operating in all 9,877 ovens for the manufacture of metallurgical coke, and the quantity of coal carbonised annually is approximately nineteen million tons.

The quantity of tar recovered per ton of coal carbonised varies from eight to eleven gallons according to the coal used and the temperature to which the tar-laden gas is exposed.

The by-product coking industry is entering upon a new phase so far as Britain is concerned, in that greater use is being made of coke-oven gas for town's use. This entails closer attention to the calorific value and purity of the gas, together with more uniform production. The time has passed when coke alone mattered, and the technique of operation of coke ovens has now much more in common with that of gas works. Especially is this the case in the handling of the liquid by-products.

The large scale coking plants dealing with sufficient tar and ammonia to justify the installation of independent plants to work up their own by-products, can secure a return of from 5/- to 8/- per ton of coal carbonised according to local conditions and their effect on the marketing of the refined products.

Recovery of the by-products.

Gas. It is quite obvious that each coke oven installation has its own peculiar problems in the efficient disposal of surplus gas. The various uses are (1) boiler firing, (2) generation of electrical and other power by gas engines, (3) town lighting, (4) fuel purposes in factories, particularly iron and steel works.

Gas-firing of steam boilers has many advantages, such as high efficiency, flexibility of control, cleanliness and ease of handling, and this method of disposal of surplus gas is available at practically all installations. With regard to uses (2), (3) and (4) above, it is unfortunate for this country that our coke oven installations are grouped into narrowly-constricted districts, coincident with the coalfields areas, as is only natural. This limits the applicability of the suggested methods of disposal.

The use of coke-oven gas for town lighting is developing rapidly, but this country does not yet rival America and Germany in this respect. Several cities and towns depend entirely or in part upon coke ovens for their gas supplies, notably, Middlesbrough, Leeds, Glasgow and Sheffield, but there is no attempt to link up towns and coke-ovens installations in the manner recently suggested and attempted in Germany, nor are long-distance transmissions, now in vogue in America, yet apparent in this country.

Research is at present being conducted upon the conversion of ethylene present in the gas into alcohol, acetic acid and ether.

Tar.—The gas evolved from the coal during the heating stage holds in suspension tar and water vapour, and these vapours are extracted by methods very similar to those employed at gas works—hydraulic mains and tar extractors being used to cleanse the gas prior to the benzol extraction process. The gas is cooled below its " dew point " and the bulk of the tar vapour is thereby condensed. The residual tar fog is caused to agglomerate by drawing or forcing the gas through fine orifices, and then causing it to impinge on plates which receive the globules of tar. In the direct system the gas remains at a higher temperature and is cleansed of tar by sprays of ammonia liquor, as in the Otto system. The higher temperature of operation produces a much more viscous tar, as the oils of lower boiling point are more liable to pass away with the gas, leaving the heavier constituents behind.

The composition of the tar varies with the temperature of carbonisation, and with the extent of exposure to hot surfaces, that is with the free space in the retorts.

This exposure decomposes the more unstable hydrocarbons, and increases the amount of so-called " free carbon " present, producing a heavy viscous tar. The composition of tars produced from the same coal, when carbonised at various temperatures, is shown in the following table given by Lewis T. Wright. The yield of gas increases with the temperature, and the following table therefore illustrates the point, although the actual temperature of carbonisation is not stated.

Coal Analysis.

Carbon	81.92%	Nitrogen	1.28%
Hydrogen	5.39%	Sulphur	1.97%
Oxygen	6.88%	Ash	2.56%

Yield of gas, cu. ft. per ton	6,600	7,200	8,900	10,162	11,700
Sp. gr. of tar	1,086	1,102	1,140	1,154	1,206
Analysis by wt. amm. liq.	1.20	1.03	1.04	1.04	0.38
Crude naphtha	9.17	9.65	3.73	3.45	0.99
Light oil	10.50	7.46	4.47	2.59	0.57
Creosote	26.45	25.83	27.29	27.33	19.44
Anthracene oil	20.32	13.57	18.13	13.77	12.28
Pitch	28.89	36.80	41.80	47.67	64.08

An average coke-oven tar has a specific gravity of 1.150 and contains 55 per cent. pitch.

There is a further variation in the quantities of naphthalene and anthracene obtained from the tars produced at different carbonising temperatures; the higher temperatures give heavy tars with high proportions of those products.

Generally speaking, coke-oven tars from high-temperature processes have less value than the lighter tars, and are not so attractive to the tar distiller. The quality of the coke, however, is of paramount importance, and there are very few instances in which the quality of tar can be regulated at the same time, beyond leaving the minimum free space in the retorts.

Rapid carbonisation in very narrow ovens, as advocated in modern practice, produces a tar containing much naphthalene, anthracene and pitch and very little naphtha. This is probably due to the rapid removal of the water in the coal, which would otherwise act as a buffer and prevent the " cracking " of the tar vapour on the heated surfaces of the retort. Any naphtha vapours produced are immediately removed with the gas, leaving heavy tar.

Considerable quantities of ammonia liquor are deposited along with the tar (except in the direct process which is designed to avoid this). A certain amount of ammonia passes with the gas. This is extracted by scrubbing with water, and the whole of the ammonia compounds are handled together as indicated later.

Various means have been employed to increase the conversion into ammonia of the nitrogen present in the coal, but coke-oven construction does permit much to be done on the lines of gas works practice

of steaming retorts, and with coke as primary product this would not be permissible. In any case, the ammonia market is now so unprofitable that there is little encouragement for further experiment in this direction.

The nitrogen present in the coal is distributed among the products of carbonisation as follows:—

Present in the coke	58.3%
,, tar	3.9%
,, liquor	17.1%
,, gas	19.5%
,, cyanogen	1.2%

This distribution is typical and subject to fairly wide variations.

The coal gas after removal of tar and ammonia still contains hydrocarbon vapours—chiefly benzol—and these are removed by scrubbing the gas with a wash oil which dissolves the benzol, etc., and gives up these products when subsequently distilled. Much progress was made during the war period in the recovery of maximum quantities of benzol and toluol. In the famous " C " process at first employed, tar was used as the washing fluid, but this was later replaced by heavy creosote oils ; " green oil " proved to be the best, and was obtained by draining anthracene oil free from salts.

The amount of benzol and toluol obtained from the gas by oil-washing is from 20 to 30 times the quantity recoverable from the tar, and in the case of the coke ovens working at high temperature, practically all the benzol is found in the gas. The gas requires further purification before it is fit for use as fuel.

Tar refining.

It is becoming more common practice for coke ovens to distil their own tar and market the primary distillation products. There is a steady and certain demand for refined tar for road-making purposes, and for pitch for use as a binder in briquette making, and these outlets absorb from 50 to 70 per cent. of the products of distillation. The balance, naphthas and creosotes, can usually be readily sold, and there is, therefore, every justification for the erection of a distillation plant in conjunction with a battery of ovens of even the smallest capacity. The larger coke-oven installations can readily proceed to the second stage of refining as indicated below, and are usually fortunate in that their products are of the highest quality, fundamentally, to gain ready markets. This presumes adequate chemical control of manufacture. The tar dealt with is fairly uniform, and having been produced from high-temperature carbonisation, is free from most of the impurities which complicate refining of gas-works tar.

Paraffins, for instance, are not found to any extent in coke-oven tar, and this facilitates the manufacture of pure benzene and toluene ; polyhydric phenols give no trouble in the preparation of high-grade disinfectants; the pitch left on distillation is sometimes preferred to other grades of pitch by the makers of briquette fuel.

Coke-oven Coal Tar, Ammonia and Benzol.

Primary products.—Sulphate of ammonia, crude benzol, light oil, naphthalene salts, creosote (drained oil), heavy creosote, refined tar, pitch.

Secondary products.—Benzene, toluene, xylene; motor spirit, solvent naphthas, high flash naphthas; pyridine, heavy bases; paracoumarone resins; naphthalene—whizzed, flake, sublimed, pure; fuel oil, Diesel oil; anthracene, carbazol, acenaphthene; green oil, greases; phenols, cresols and high boiling acids; cresylic creosotes and disinfectant fluids; pitch coke.

Up till comparatively recently the usual procedure in tar distilling was to allow the tar to settle for as long a period as possible in order that the entangled ammonia liquor might rise to the surface. The settled tar was charged to a " pot " still, constructed of mild steel, which was then heated by a coal fire. By prolonged gentle heating the remaining water was distilled off, and when the distillate was free from water the heat was increased, and oil thereby distilled off up to the desired point. The vapours were condensed by passing them through cast-iron coils surrounded by water.

In conformity with the general trend of modern methods of manufacture, fuel and time-saving innovations are being developed. The first step was to use tar instead of water for cooling the coils. This conserved heat and partially removed the water from the tar used for cooling purposes, and a natural elaboration of the principle was to make the process continuous.

In one continuous tar distillation system, there is a series of stills through which the tar is passing, being continually raised in temperature during transit. The last still is that in which the pitch residue is being formed, and the vapours from this, evolved at a high temperature, are condensed by the tar in the still next in series, which tar is thereby heated and gives off vapours to the third still, and so on. This type of plant is becoming very popular, but has the defect, inherent to all tar distilling, that unsettled watery tar is very difficult to deal with. The removal of water cannot be " forced " without grave risk of frothing.

Another continuous distillation plant is designed to overcome this difficulty by avoiding the presence of any considerable bulk of tar in process at any time, and by improving the control of the heat applied. Fire heating is subject to too wide fluctuations for efficient working in continuous processes, and the system referred to utilises a lead bath as heating medium, and thus introduces considerable heat inertia into the operation. A shallow stream of tar flows through a " labyrinth " over the surface of the molten lead and is thus distilled to the desired stage. The rate of flow of very watery tar can be regulated until no danger of frothing occurs.

Much the same effect is attained in quite a different manner by a plant designed to produce refined tar for road-making purposes. In this case the tar is heated while passing under pressure through coils heated by furnace gases, which raises the tar to a temperature well above the point at which its lower boiling constituents will distil when the tar emerges from the coils. The water, naphtha and part of the oil are thus vaporised and removed, leaving the road tar of the required consistency.

Dehydration.

The latest progress in this branch of the industry deals purely with the problem of dehydration, and a recently patented system is designed to act as a forerunner to any of the above processes of complete distillation. It has been pointed out above, that prolonged gentle heating is desirable for the removal of water, and the heating medium selected in this case is steam at normal factory pressures. Steam is passed through coils immersed just below the surface of tar contained in a well-insulated vessel ; the heated tar naturally remains near the surface. Water vapour is driven off and passes through coils submerged in the body of the tar and is thereby condensed. The heat is thus transferred to the tar and assists disentanglement of water which rises to the vicinity of the steam coils and is there vaporised. By regulating the supply and controlling the level of the tar, the process is made continuous, and dry, heated tar overflows for use in any type of distillation plant. It has been proved that steam generated under normally efficient conditions and used in this manner is more economical than direct firing for the removal of water from tar. The process is particularly valuable for dealing with tar of low specific gravity, such as is encountered in low-temperature carbonisation and in the carbonisation of semi-lignite coal. This low specific gravity tar holds water in suspension very tenaciously, and is most difficult to distil by the usual methods.

The separation of water from tar in cases such as those last enumerated has been successfully accomplished on a commercial scale by means of super-centrifugal machines, but the capital outlay involved has handicapped development in this direction in cases where simpler methods are in vogue.

Naturally in coke-oven tar-distillation plants it is often feasible to utilise surplus gas as the source of heat for tar distillation, and where this is used, very delicate heat control is possible. In at least one large tar distillery the use of raw coal is forbidden, and only coke breeze is used at the steam boilers and at the stills, and this experiment in coal conservation has been very successful.

The various fractions obtained in a simple distillation have uses in commerce. The naphtha and light oil are usually sold to distillers who carry out the refining to secondary products. Creosote is very extensively used for the preservation of timber ; the naphthalene and phenols contained in crude creosote are regarded as the most valuable constituents for this purpose. About one gallon of creosote is absorbed by a cubic foot of timber during the " pickling."

Refined tar—essentially a mixture of pitch and creosote—is in great demand for road making, both for grouting the stone and for surfacing. Coke-oven tar, after refinement, is often mixed with bitumen for road work in order that certain advantages of plasticity inherent to the bitumen may be utilised without the defect of skidding being observed. In tarring stones, about 10 gallons of tar are used per ton of stone, and in surfacing a road, one gallon of tar covers about six square yards.

Uses of pitch.

Pitch has a ready market for the manufacture of briquettes. Small coal is " wetted " with molten pitch and compressed into uniformly shaped blocks. On cooling, the blocks are resistant to ordinary handling. The annual production in this country is over one million tons, and 8-10 per cent. of pitch is required for binding purposes.

A similar use of pitch is found in the electrical industry for the manufacture of electrodes. Specially selected carbon is bound by pitch and the whole is recarbonised. An excellent carbon for the purpose may be obtained from pitch itself by heating it strongly in suitable stills. Industries extracting metals from salts by electrolysis are large consumers of pitch for electrode manufacture.

In times of low market values of pitch, attempts have been made to use it for household fuel, either by making mixtures of coal and very hard pitch, or by converting the pitch to pitch coke, which is attractive as a fuel on account of its freedom from ash and the high radiant heat obtained on combustion.

In the case of the products of the second stage of refinement, the markets are subject to great fluctuations, but the products from coke-oven tar can usually be disposed of quite readily.

By far the largest use for the products obtained on refining crude benzol is for motor spirit. Standard specification motor benzol gives a ton-mileage per gallon 25 per cent. higher than present-day petrol, and has other advantages, such as less tendency to " knock," and mixtures of benzol and petrol are very popular for motor fuel.

Coke-oven benzol is the chief source of benzene and toluene for explosives and synthetic drugs and dyes, being preferred in this respect on account of the absence of paraffins and unsaturated bodies. Large quantities of aniline are manufactured from this benzol, and the dyestuffs industry is founded on this commodity. Toluene has similar uses for dyes and perfumes, but is peculiarly suitable for the manufacture of high explosives. Xylene, on the other hand, is of little use for the latter purpose, but is a valuable starting point for perfumes and essences. Unseparated, but chemically pure, mixtures of toluene and xylene are very largely used as solvents in the rubber industry and as dry-cleaning fluids, being preferable for these purposes on account of their lower toxicity. Heavier fractions of the naphtha products are used for solvents in paint and anti-corrosive compound manufacture.

All these naphthas are prepared from the crude material by treating it with sulphuric acid and caustic soda, and redistilling through a fractionating column. Among the by-products of this purification are pyridine bases and paracoumarone. The bases on further purification yield pyridine, which is one of the common denaturants used to render alcohol non-potable. Substitutes have been permitted recently and there is a smaller demand for pyridine for this purpose. Pyridine is a valuable organic solvent, but the odour is detrimental to its extensive use.

Paracoumarone is a solid resin, an excellent substitute for the natural pine resin, and having specialised use in the preparation of oil varnishes for woodwork, and for admixture with rubber for the manufacture of hard-wearing rubber. The resin has very high electrical resistance and is largely used in insulation preparations.

Naphthalene.

By far the greater proportion of naphthalene is used in the crude state for the manufacture of fire-lighters, and fairly large quantities of pure naphthalene are used in the dyestuffs industry.

The refining is done by exuding the creosote under hydraulic pressure, and treating the pressed salts, after melting, with sulphuric acid and caustic soda, and redistilling. The chemically pure product is the starting-point of many important dyes, notably indigo. As in the case of most pure secondary coal-

tar products, naphthalene is used for the manufacture of certain drugs, explosives and photographic chemicals, but it is not important in this respect. The largest single application of pure naphthalene is in the manufacture of beta-naphthol, of which thousands of tons are used yearly for making dyes.

Creosote from which the naphthalene has been removed is valuable for fuel oil for internal combustion engines of the Diesel type, and for combustion in oil fuel furnaces, such as are used for heating rivets and small metal work. The petroleum oils are cheaper for these purposes than creosote, on account of the demand for creosote for wood preservation, for which purpose the petroleum oils are of little value.

Anthracene.

Anthracene salts are deposited from heavy creosote and are purified by centrifuging and pressing to free the salts from oil. The anthracene is further purified by washing with pyridine and then sublimed. From the pure product is prepared anthraquinone, which is the basis for many important dyes, notably those of the alizarine group. For this preparation it is very essential that paraffinoid substances should be excluded, and it is in this respect that coke-oven tar scores heavily over other tars.

Anthracene has no commercial use other than as a source for dyestuffs, and similarly the compounds associated with it, and removed in the pyridine washing, namely, carbazole and phenanthrene are used only for the same manufactures. Carbazole is the source of very fast dark blue dyes, which are competing with indigo. Phenanthrene and acenaphthene have a possible future in the manufacture of synthetic tannins.

The oil drained from anthracene is widely used as a wash oil for the absorption of benzol vapour, for timber creosote and fuel oil, for fluxing pitch and for lubricating the clay moulds in brick manufacture. It is also extensively used in the preparation of greases for use in lubricating wire ropes, such as are used in mines, etc.

The tar acids or phenols, which include carbolic and cresylic acids, are mostly used for disinfectant manufacture. Coal tar is by far the most important source of the raw materials for disinfectants. The coke-oven tar phenols can easily be refined to give products conforming to the stringent specifications laid down by manufacturers of high-grade disinfectants and resins, in which freedom from colour is essential. Absolute phenol is such an important and familiar disinfectant that it has long been the unit used in determining the bactericidal efficiency of disinfectant preparations. It is the active constituent of lysol and similar solutions, and is largely blended into soaps and powders. Cresylic acid has greater disinfectant power and is also less dangerous to animals, and is consequently widely used in disinfectant work. Higher homologues have still higher coefficients of bactericidal power, and are more pleasantly aromatic and naturally command higher prices. The largest single application of cresylic acid as disinfectant is in the preparation of sheep dips—which term includes general disinfectants for farm work—and for this purpose it is usually diluted with creosote. The mixture known as cresylic creosote is saponified with some emulsifying compound, such as rosin soap, and the resulting fluid is added to water when required for use. Dispersed in the water-oil emulsion thus formed, the cresylic acid is a powerful disinfectant.

Phenol and cresylic acid.

Carbolic acid (true phenol) was formerly a very important raw material for the high explosive lyddite used for shell filling, but the development of T.N.T. has eclipsed this importance. Picric acid (lyddite) is, however, still important as a starting point for other explosives and for dyestuffs manufacture.

A modern and highly important application of phenol and cresylic acid is the preparation of phenol-formaldehyde synthetic resins, exploited by Baekeland and his partners under the trade name "Bakelite." These resins have unique properties. In most cases they are hard, infusible, insoluble substances which can be moulded when freshly prepared, and later turned and drilled. They have high electrical insulation values and are widely used to replace hard rubber and ebonite. Other grades of these resins can be used as substitutes for amber and natural resins.

Mechanical separation of associated solids such as coal and stone, ore and earth, etc., can now be carried out by the froth flotation method, which makes use of differences in density and surface tension between the substances. The froth is produced by adding to the wash water used some phenol prepara-

tion, either crude tar acids or cresylic creosote. This method of separation has proved to be very economical and very convenient, and thousands of gallons of acid are exported monthly for this purpose.

The phenols are of importance in the fine chemical branch of industry as a basis for the manufacture of most of the developers used in photography. Salicylic acid is of great importance in the pharmaceutical branch of chemistry, and is derived from phenol. Aspirin, the well-known pharmaceutical preparation, is a derivative of salicylic acid.

The above outline of the uses of coal-tar products is a mere summary of the most important applications from a commercial standpoint. The fine (organic) chemical industry depends entirely upon coal tar for its supplies of aromatic hydrocarbons, and the national income is much augmented by this industry. The story of the foundation of the coal-tar dyes industry in this country, and the vicissitudes through which it passed before reaching its present state of eminence, are familiar to all, and demonstrate the national importance of the by-products industry.

Sulphate of ammonia.

The ammonia branch of by-product recovery is at present passing through a period of depression and anxiety. The development of the uses of sulphate of ammonia for artificial manure was so great that much capital has been expended on the exploitation of synthetic methods of manufacture, with the result that to-day the old-established processes are threatened with extinction.

In by-product coking the gas, containing ammonia, may be passed through sulphuric acid which converts the ammonia into sulphate of ammonia. In the case of plants in which the gas is cooled to deposit tar and ammonia liquor, the liquor is separated and the ammonia distilled off this liquor into sulphuric acid. Up to the end of the war period, the bulk of the sulphate produced in this country was very crude, containing much free acid and water, and very lumpy and grey in colour. Foreign competition compelled the introduction of improvements, and at present the major part of the sulphate produced is in the form of separate crystals, dry, neutral and powdery, and therefore easily spread by farmers. Despite this the price obtained has fallen and in most cases sulphate is made at a loss. It is necessary to remove the ammonia from the gas, and the liquor cannot be diverted to drains or streams, and the only course open to manufacturers is to make the highest grade of sulphate as cheaply as possible. This state of affairs results entirely from the enormous scale of operation of the synthetic processes which have only air, water and gypsum as their raw materials, and which have the added advantage that their production of sulphate is in a physical condition very suitable for farmers. The demand for sulphate is increasing yearly, but paradoxically the price is falling yearly.

Coke-oven gas is freed from sulphuretted hydrogen by passing it through beds of bog-ore (iron oxide), which ultimately become laden with free sulphur; the spent oxide is usually sent to acid works which burn off the sulphur and convert it into sulphuric acid, which is largely used for the manufacture of sulphate of ammonia.

Since the advent of synthetic sulphate of ammonia, which does not require sulphuric acid for its manufacture, there has been a falling off in the demand for the acid, and consequently the acid makers do not require all the spent oxide produced. This reflects on the prices obtainable for the spent oxide, and thus both ammonia and oxide are sources of anxiety for the by-product coke-oven owners. The obvious solution of the problem is to combine the two products at the works and be independent of outside manufacturers of acid, and much research is being conducted to achieve this end. There is apparently no necessity to make acid from the sulphur. One line of research is endeavouring to proceed from the sulphuretted hydrogen to sulphate of ammonia via zinc salts, another line is investigating the feasibility of combining ammonia gas and sulphur dioxide obtained by burning spent oxide and subsequently oxidising the resulting sulphite to sulphate of ammonia.

The whole problem is one of the most serious ever presented to the carbonising industry, and a solution is awaited with great anxiety. Meantime, there are distinct possibilities of producing synthetically at a low cost, various ammonium salts from the surplus gas, using the hydrogen contained therein instead of that produced by other means.

Chapter 4.

THE TESTING OF COKE.

By Prof. R. V. Wheeler, D.Sc.

The tests that it has been found desirable to carry out on coke, can be divided into physical tests and chemical tests. The chemical tests, in general, are well known and present but little difficulty, at all events as regards obtaining results of sufficient accuracy for the purpose to which industrial analyses are usually put. The interpretation of chemical analyses of coke is also determined by well-recognised rules. Thus the blast-furnace manager knows that his coke should not contain more than a certain percentage of sulphur nor some equally definite percentage of phosphorus. The amounts have been fixed by long-standing usage, but whether they have any definite scientific basis is somewhat uncertain.

With the physical tests, on the other hand, the matter is somewhat different. The tests are mainly empirical, and the value of the information that they yield is not a precise quantity. The standardisation of physical tests has been the subject of much study in the United States of America, and the Bureau of Mines and the American Society of Testing Materials have specified standard methods of testing. Although the physical tests at present afford no absolute information, they do nevertheless tell the user whether the coke conforms to certain arbitrary specifications, and these arbitrary specifications yield a standard of quality which, even if of no scientific value, appear to fulfil the not unimportant function of ensuring that the coke delivered at the ironworks shall be uniform in character. Moreover, cokes which conform with these arbitrary standards appear to give good results in the blast furnace.

The dominant factor with regard to the physical properties of a metallurgical coke, is the character of the coal carbonised, but differences in the mode of carbonisation also have a considerable effect. For example, cokes made from the South Wales coking coals, containing on the ash-free dry coal about 90 per cent. of carbon and 20 per cent. of volatile matter, are dense, hard and blocky. The pores are small, and the fracturing of each piece is irregular and infrequent, so that these cokes offer a marked resistance to breakage. Their appearance is generally dull. Cokes made from Durham coking coals, containing from 86 to 89 per cent. of carbon, and 25 to 30 per cent. of volatile matter, are also dense, hard and blocky, with small pores. Fractures usually occur more frequently than in the cokes from South Wales coals, so that their resistance to breakage is less. Durham cokes frequently possess a silvery-grey lustre, both on the external surface of each piece of coke, and on broken faces exposed at random. Cokes made from the coals of lower carbon content (less than 86 per cent.) and containing more volatile matter (over 30 per cent.), such as are widely used in Yorkshire, Derbyshire, Cumberland, Staffordshire and Lancashire, have properties which are markedly different from those of the South Wales and Durham cokes.

The properties of cokes from such low-carbon coals are probably more affected by the methods of carbonising than are those of South Wales and Durham cokes, the method of charging the oven being apparently of particular importance. For example, such a coal, when charged into an oven in a compressed state, yields a coke which is very dense and heavy, but the fractures developed are numerous and are sharply defined. The resistance to breakage is consequently low. The coke is not blocky, but frequently exhibits a fingery structure; it may be hard and dense, but brittle. When, however, such a coal is top-charged into an oven without compression, the coke produced is usually light (of low apparent specific gravity) because of the large pores developed. The fracturing is more irregular than in cokes made from compressed coals, and the resistance to fracture is higher. Cokes made from these low-carbon coals may possess a silvery lustre, but as the amount of volatile matter increases until the coal is almost non-caking, the surface again becomes dull.

The density and the frequency of occurrence of fractures in a piece of coke vary according to its position in the oven, for example, as regards the distance from the oven sole in the height of an oven, or, as regards the distance from an oven wall in the width of an oven. It is not, therefore, possible to select one piece of coke which will be representative of the charge from one oven, or of the output from

a number of ovens. Still less can a portion of a normal piece of coke (the length of which is somewhat less than half the oven-width) be selected for such a test as that of ultimate strength. Moreover, since it has been shown that the maximum load which coke has to withstand in passing down a blast furnace is only of the order of 30 lbs. per sq. in., whereas the averege crushing strength of a metallurgical coke approaches 2,000 lbs. per sq. in., it is misleading to judge its strength by such methods as are commonly used for testing homogeneous materials.

It will be clear from these considerations, that any method of assessing the strength of a coke must be based on the testing of a large number of pieces to obtain an average result. This requirement is fulfilled by the so-called " Shatter " test, in which 50 lbs. of run-of-oven coke (over 2in. size) is used. Even with this test, it has been found necessary to perform a series of at least three before a reliable index for resistance to breakage is obtained (the " Shatter Index "). The Shatter Index is a measure of the liability of a coke to form breeze on dropping. Since dropping during loading and unloading the coke, between the coke-oven plant and the blast-furnace plant, induces the most severe mechanical strain to which coke is subjected before it is burnt at the tuyeres of a blast furnace, it has been found to be the most satisfactory measure of coke " strength."

Another test, which fulfils the requirement of using a large number of pieces of coke to obtain an average effect, is the " barrel " abrasion test, which measures the coherence of a coke, or its liability to produce breeze under mechanical attrition or abrasion during its passage down the shaft of a blast furnace.

Another important test for coke is a measure of its " combustibility " or ease of reaction with air, and also its reactivity with carbon dioxide. The results of a satisfactory combustibility test should enable one to say whether one coke burns more quickly than another at the temperatures attained near the tuyeres of a blast furnace. Reactivity tests should indicate how quickly a reducing atmosphere is produced above the level of the tuyeres, and should also indicate the liability to " solution " loss in the shaft of the furnace.

Other physical tests are the determination of real and apparent specific gravity, and percentage porosity. A knowledge of the apparent specific gravity is of use when coke is charged to a furnace by volume. The determination of the real specific gravity is necessary in order to calculate the percentage porosity. Undue significance should not be given to this latter quality, since it would appear more rational, when studying combustion phenomena, to consider the total surface area of the pores rather than their percentage volume.

Sampling.

The first essential of making a satisfactory analysis of a consignment of coke is to obtain a representative sample. It is well known to coal samplers that the easiest grade of coal to sample is washed slack. In this material the ash content is not high, and the treatment in the washer mixes the coal well. Consequently, the coke which is made from this material is fairly uniform in composition, and run-of-oven coke is much easier to sample than run-of-mine coal. A complication is introduced by the admixture of slurry (containing, say, 20 per cent. of ash) with the washed slack (containing, say, 6 per cent. of ash) for the oven charge, since wet slurry cannot be uniformly distributed. In sampling coke for daily consignments to blast furnaces, any errors arising from the selection of only a small gross daily sample may be compensated for by taking a weekly or monthly average of the results obtained.

These considerations apply to the sampling of coke for chemical examination, namely the determination of ash, sulphur and phosphorous. A sample selected for the determination of moisture or volatile matter is subject to greater errors. When the coke is quenched on an inclined bench, the exposed pieces of coke are usually the wettest. The coke from the centre of the oven has a greater content of volatile matter than has the coke from near the oven wall, which has been subjected to more prolonged heating. It is desirable that standard methods of coke sampling, suitable for all conditions of coke handling, should be introduced by some competent authority.

A suggested method of coke sampling, based on the method used for sampling coal shipments, is as follows :—When the coke passes into waggons over screens, a metal scoop may be held in the stream of coke for a few moments, in order to obtain a complete cross-section of the stream. This is done periodi-

cally at specified intervals, and when a sample of at least half a ton has been collected it is crushed, coned and quartered in the usual way. This method may be too onerous for daily use but would be useful in checking methods of sampling employed by the coke vendor and buyer.

In grinding coke samples, care should be taken to avoid the use of grinding materials which would contaminate the sample with iron through the abrasive action of the coke. It has been found by American investigators that the use of cast-iron bucking boards and disc pulverisers led to severe iron contamination, and only porcelain-lined ball-mills using flint pebbles, or steel rolls and diamond-steel mortars, were satisfactory. Wedgewood and agate mortars are also suitable, but their use involves much mechanical effort. Care should, however, be taken that coke is not ground with any materials made of iron.

The Shatter test.

The shatter test was recommended for adoption as a standard in 1923, by the Coal and Coke Committee of the American Society of Testing Materials. The test plant, illustrated in Fig. 1, conforms to the

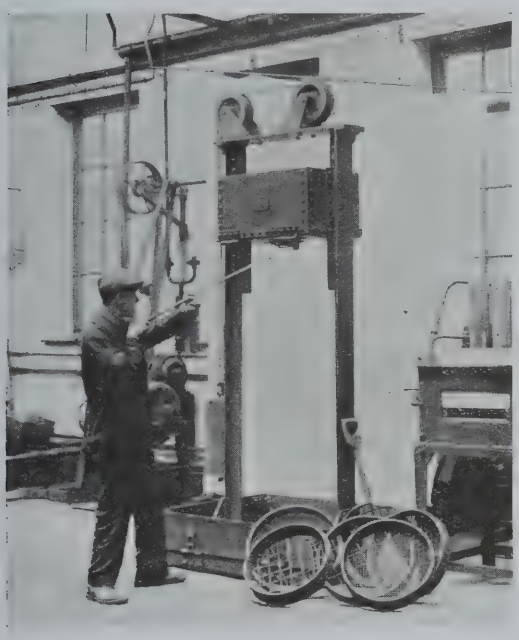


FIG. 1.—*Apparatus for "Shatter" Test.*

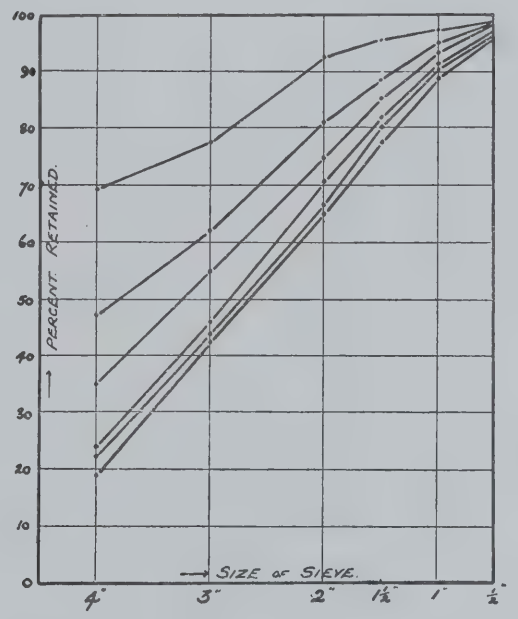


FIG. 2.—*Typical Coke Results of "Shatter" Test of Coke.*

dimensions and specification recommended by the Committee as "a convenient form of shatter-test machine," and is in use at Sheffield University. The basis of the test is the dropping of 50 lbs. of coke (greater than 2 ins. in size), four times successively, from a height of 6 feet. The resultant coke pieces are then screened over a 2-in. sieve (and over smaller additional sieves if desired), and the percentage which remains on a screen of 2-in. mesh is called the "Shatter Index."

The coke is placed in a metal box, 18 ins. wide, 28 ins. long, and 15 ins. deep, which is supported above a ½-in. metal base-plate rigidly mounted. It is so arranged that the inside of the bottom of the box is at a distance of 6 ft. above the top of the base-plate. The bottom of the box consists of two doors hinged lengthwise and latched so that they will swing open freely, and not impede the fall of the coke. When the doors are unhinged, the coke falls the height of 6 ft. on to the metal base-plate, around which steel plates about 8 ins. high are placed, in order that no coke may be lost. Two pulleys are attached to the top of the frame, so that the box can be lowered readily by means of ropes and counter-weights.

Table I. gives the Shatter Indices of a number of cokes examined for the Blast Furnace Coke Research Committee (Yorkshire and Derbyshire Coalfields).

The shatter test results for the cokes of each district exhibit some similarity, whilst the average values for the various districts fall into an order which is the order generally assigned to the groups of cokes in metallurgical practice. For example, South Wales cokes and the better qualities of Durham cokes,

TABLE I.—AVERAGE RESULTS OF SHATTER TESTS OF COKE.

Lab. No.	Origin.	Shatter Index.	Average for Districts.
1	S. Wales.	93.9	91.0
14	do.	88.2	
6	Durham.	79.7	
2	do.	73.2	72.6
5	do.	65.0	
3	S. Yorkshire.	71.3	
13	do.	71.0	
4	do.	62.1	64.4
3b.	do.	61.7	
7	do.	55.8	
15	Derbyshire.	45.1	45.1
10	Westphalian.	88.7	88.4
11	do.	88.1	

are used in cupola practice. Whilst, in general, South Yorkshire and Derbyshire cokes are not used for this purpose, since their mechanical strength is insufficient. The two Westphalian cokes referred to were used in England during the stoppage in the mining industry in 1926, and were found to be superior to the Durham cokes previously used, under the same conditions, in cupola and blast-furnace practice. The Durham coke No. 6, with a Shatter Index of 79.7, was found to effect an appreciable coke saving per ton of pig iron compared with the Durham coke No. 5 (with a Shatter Index of 65.0), under the same conditions. Admixture of a proportion of South Wales coke, No. 1, with a Yorkshire coke, effected a considerable reduction in the amount of coke used per ton of pig.

The comparison of various pairs of cokes in the series given in Table I., under the same furnace conditions, has enabled the tentative conclusion to be drawn that the Shatter Index of a coke is an index also of its general blast-furnace value.

The experimental work has also enabled the following conclusions to be drawn:—

(1). The mean of three shatter tests only differs from the average of a large number of tests by less than one per cent.

(2). The shatter indices for different sizes of coke over 2 in. minimum size (for example 2 to 3 in., 3 to 4 in. or over), are approximately the same.

(3). At least three, and preferably four, drops are necessary for comparative tests.

Fig. 2 illustrates the effect of successive drops in inducing breakage of coke originally over 4-in. size. The largest coke (over 4-in.) breaks up the most readily, and the smallest size (through $\frac{1}{2}$-in.) the least in successive drops. After 4 drops (and in some cases after 3 drops), a straight line curve relating the breakage of the different sizes of coke is obtained. Subsequent drops induce only a relatively small amount of breakage and the linear relationship persists. This result explains the second conclusion referred to.

Abrasion test.

The abrasion tests used at Sheffield University are of two types. One conforms to the essential requirement of using a large weight of coke (25 lbs.), which is rotated in a ball-mill at a speed of about

20 R.P.M. for a suitable interval of time. The other uses only one piece of coke which, after being ground to approximately cubical shape, is held against a rotating emery wheel for specified intervals of time. A lever balance-weight allows the pressure exerted during abrasion to be varied. This test, whilst not giving absolute results, may be used to compare the relative abradabilities of different cokes, and allows the influence of pressure to be examined.

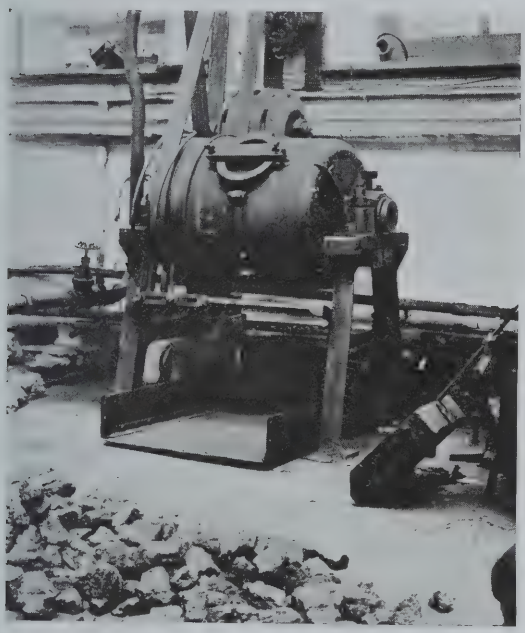


FIG. 3.—*Apparatus for "Barrel" Abrasion Test.*

In the "barrel" abrasion testing apparatus, illustrated in Fig. 3, a charge of 25 lbs. of 2- to 3-in. size coke occupies over 80 per cent. of the effective volume of the barrel, to which false ends are fitted.

It has been found that the percentage of the effective volume occupied by the coke exerts a marked effect on the breakage and wearing of the coke. It is also necessary to restrict the shatter effect introduced when only a small percentage of the volume of the barrel is occupied by coke, to obtain a more reliable result for abrasion losses. When there is only a small amount of free space, the coke is prevented from dropping, and the pieces roll and slide over each other. By comparing samples of coke which have passed down the shaft of a blast furnace, with the appearance of the same coke which has been treated for varying periods in the barrel abrasion test apparatus, it has been found that treatment under the conditions specified for an interval of 30 mins. induces a similar appearance of rubbed edges. A screen analysis of a South Wales' coke (No. 1) after such treatment is as follows:—

Size.	Weight. lb. oz.
Over 2 in.	22—6
2—1½ in.	1—3
1½—1 in.	0—2
1—½ in.	0—2
½—1/16 in.	0—3
Through 1/16 in. ..	1—0
	25—0

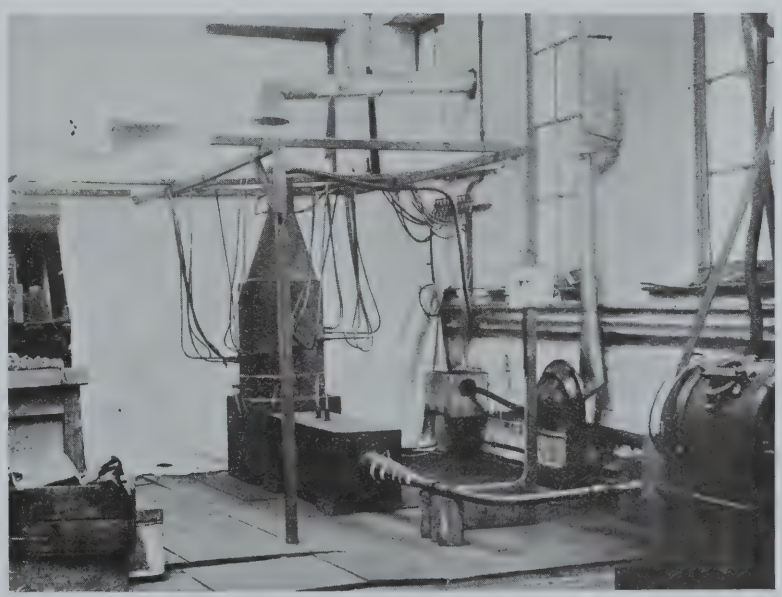


FIG. 4.—*Apparatus for determining the relative combustibility of Coke.*

The most notable result is the amount of fine dust (less than 1/16in.) produced. Expressing this as a percentage on the total, as the index of abrasion, typical results for a number of cokes are as follow:—

South Wales, 4.0, 1.5; Durham, 1.0; Cumberland, 1.5, 1.0; S. Yorks, 1.5, 3.3, 1.3; Derbyshire, 3.5. No correlation between the blast-furnace value of a coke and its index of abrasion has been possible, but the order of the loss of coke by abrasion appears to be but small and unlikely to account for large differences

in coke consumption in the furnace. Abrasion tests have not yet been found to be of positive value for testing cokes drawn from a number of counties; nevertheless, certain barrel abrasion tests have been found to be useful for routine testing of similar types of coke at a blast furnace.*

Combustibility and reactivity tests.

Since by far the largest proportion of metallurgical coke is used in blast furnaces, a combustibility test, which is designed to measure the rate at which air reacts with coke, must reproduce some of the conditions, notably that of temperature, at which coke is burnt near the blast-furnace tuyeres. The most satisfactory test so far designed to meet these requirements is that worked out by the American Bureau of Mines investigators.† A similar furnace in use at Sheffield University is illustrated in Fig. 4.

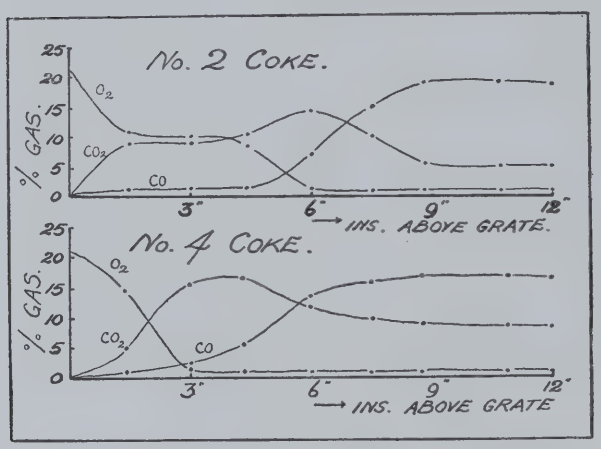


FIG. 5.—*Typical Gas Analyses obtained during "Combustibility" Test of Coke.*

The furnace is of cylindrical section, and of 1 sq. ft. grate area; the furnace lining is made of sillimanite, and the grate bars may be rocked by means of a cam and an external lever. At intervals of 1½in. above the grate level, there are openings in the furnace lining and metal casing stepped round the circumference for ease of access. Through these openings, gas-sampling tubes may be inserted into the coke-bed, and the temperatures may be measured with an optical pyrometer. The gas-sampling tubes are made of three thin copper tubes; through the two annular spaces water circulates for cooling purposes, and the gas sample is drawn through the central tube. Arrangements are made for drawing off gas samples, and collecting a proportion of the gas stream over mercury. Air is supplied to the furnace by a fan, the amount of air entering being measured by a venturi meter. The temperature and pressure of the air can also be measured.

In operation, a supply of coke of suitable size (1 to 1½in., for example) is prepared, and a fire started with the aid of a gas-burner. A 12-in. bed is built up. When the bed has attained equilibrium, temperatures are taken of the coke-bed at all the sampling points, the gas samplers are inserted, and the aspirator started. When all the sampling tubes are filled with gas a proportion of each stream is drawn off into each gas-sampling tube by running out the mercury. Samples are collected over a period of 1 to 2 minutes. A second set of samples is collected after recharging the fuel bed, and finally the temperatures are again taken.

During these tests the bed is kept at approximately 12-in. depth by charging weighed amounts of coke at suitable intervals. The weight of coke burnt per sq. ft. of grate area per hour and the volume of air supplied are therefore known. In a series of tests specified amounts of air are supplied. For example, for Rate No. 3 the amount of air supplied is three times that used for Rate No. 1, and so on. In this way tests have been carried out by burning different cokes of the same size at varying rates of air supply. Typical results of the resulting gas analyses are given in Fig. 5, from which it will be seen that the oxygen of the blast reacts with the coke to form carbon dioxide, which is partly reduced in the higher levels of the fuel bed to carbon monoxide.

The distance from the grate at which the oxygen of the blast disappears is shown for a series of cokes in Table II.

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*Cochrane, Journ. I. S. Inst., 1918, 1, 141; Hewson, Journ. Soc. Chem. Ind., 1918, 37, 60 T; Rice, Amer. Inst. Min. Eng., 1921.
†Kreisinger, Ovitz and Augustine, Technical Paper No. 137, 1916; Sherman and Blizzard, Trans. Am. Inst. Min. Eng., 1923.

TABLE II.

Coke No.	1.	2.	3.	4.	5.	6.
Origin.	S. Wales.	Durham.	S. Yorkshire.	Durham.		
Distance (inches) from grate when oxygen disappears.						
Rate No. 1.	5.	4.	3.5	4.	4.	4.
Rate No. 3.	4.	6.	5.	3.	6.	6.
Distance from grate when gas contains more than 20% CO.						
Rate No. 1.	11.	12.	7.	8.	9.	12.
Rate No. 3.	12.	12.	9.	7.	12.	12.
Average steady temps. of lower 6in. of bed (°C.).						
Rate No. 1.	1561	1587	1516	1518	1465	1506
Rate No. 3.	1712	1692	1656	1686	1645	1660
Mean "Combustibilities" of Cokes.						
Rate No. 1.	74.3	74.3	81.2	81.2	80.4	71.3
Rate No. 3.	71.0	70.7	75.6	82.2	71.9	72.7

It will be seen that the oxygen of the blast reacts the most readily with the Yorkshire cokes Nos. 3 and 4, and the least readily with Durham cokes Nos. 2, 5 and 6.

Those cokes which react the most readily with oxygen, also react the most readily with carbon dioxide. As an index of the rate of reaction of the cokes with carbon dioxide, the figures for the distance from the grate when the blast contains more than 20 per cent. of carbon monoxide are recorded in Table II. Cokes Nos. 3 and 4 react with carbon dioxide more readily than do the other cokes. It has been stated by Korevaar, Howland, Koppers and others, that the more readily a coke reacts with oxygen, the higher would be the temperature produced. This is a theoretical expectation, and is shown to be erroneous by the determinations of the temperatures in the fuel bed recorded in Table II. In this series of tests, those cokes (Nos. 1, 2 and 6) which are the least reactive with oxygen and carbon dioxide give the highest temperatures.

The mean combustibilities of the cokes may be calculated from the ratio $\frac{CO_2+CO}{2CO_2+CO+2O_2}$ which expresses the percentage of gaseous carbon found as a percentage of the maximum amount possible. These mean combustibilities have been calculated for the six cokes (Table II.), by taking the gas analysis at a level $1\frac{1}{2}$ins. from the top of the fuel bed to obviate any error due to inleakage of air, either over the top of the bed or passing up near the lining of the furnace unconsumed. It will be observed that the better blast-furnace cokes (Nos. 1, 2 and 6) have lower combustibility values than the poorer blast-furnace cokes (Nos. 3, 4 and 5).

The trend of the results is to show that easy combustibility is not desirable in a blast-furnace coke. Experiments have been carried out at H.M. Fuel Research Station using their standard method of determining the reactivity of cokes towards carbon dioxide. In these tests, in which crushed fine coke is subjected to the action of carbon dioxide at 900° C., the reactivity is expressed as the volume of carbon monoxide resulting from the passage of 100 cc. of carbon dioxide. The reactivities of the six cokes of Table II. were as follow:—

Coke No.	1	2	3	4	5	6
Reactivity.	73	98	125	162	123	72

Thus, again, those cokes which are the best blast-furnace cokes are the least reactive with carbon dioxide.

Apparent and real specific gravity.

The method of determining the apparent specific gravity, which conforms to the ideal of testing previously considered, is the method suggested as a tentative standard by the Coal and Coke Committee and the American Society for Testing Materials. In this tentative standard method, it is proposed to use a representative sample of 25 lbs. of coke in each determination, but since for each piece of coke the variation in the apparent density is great between the end near the wall of the oven and that near the centre, the use of a number of full-length coke pieces, in a series of successive tests, using one piece at a time, has certain advantages.

The apparatus consists of a tank large enough to hold a complete piece of coke of length approximately half the width of an oven. An overflow pipe is provided near the top of the tank. Inside, a wire cage fitted with a wire lid is placed. A piece of coke of full length, after being dried on a hot-plate, is weighed, fixed in the cage, and immersed in the water for a standard time (15 mins.); the cage is then raised to allow the coke to drain, after which it is again weighed. The weight of water displaced by the coke is noted and then added to the weight of water absorbed by the coke. This quantity, divided into the dry weight of the coke, gives the apparent specific gravity.

The real specific gravity is usually determined by exhausting under water a weighed sample of coke ground through 60 mesh (or, where possible, 200 mesh) in a specific gravity bottle, heated by a water bath. A rubber connexion at the top of the bottle may be opened under water after, say, one hour's treatment, to fill the bottle completely with water and avoid floating flakes of material. The true specific gravity is given by the formula:—

$$\text{True specific gravity} = \frac{W}{W-(W^1-P)},$$

in which W=weight in grams of dry coke; W^1=weight in grams of flask and dry coke plus water required to fill; P=weight in grams of flask plus water required to fill. The percentage porosity is calculated from the formula:—

$$\text{Porosity} = \frac{\text{True specific gravity} - \text{Apparent specific gravity}}{\text{True specific gravity}} \times 100.$$

Examination of porous structure.

As previously mentioned, the area of the pore surfaces may be of more significance in combustion phenomena than the actual volume of pore space. No method has yet been devised to obtain this factor, but it is possible that the use of Rose's method of coke sectioning may prove of value. Rose's method, as used at Sheffield University, consists in enclosing a full-length piece of coke in a mould of plaster of paris containing 2 per cent. of magnesia. When the mould is hard, it is cut once longitudinally and twice transversely with a carborundum cutting wheel, and the cut faces are filled in with the white composition used for moulding. The faces are wet ground with various grades of carborundum powder on a glass plate until a plane surface is obtained. The surface may be polished with alumina, if desired.

An examination of the ground surfaces shows the development of fractures, and under magnification reveals the porous structure. This method has been mostly used to study fractures (which are found to increase in number and extent with the poorer cokes of low Shatter Indices), but could be used to determine the average diameter of the pores, to obtain the superficial pore area.

COAL GAS.

Chapter 1.

THE PRINCIPLES AND PRACTICE OF COAL GAS PRODUCTION.

By T. Campbell Finlayson, M.Sc., A.M.I.Chem.E.

The earliest forms of carbonising plant consisted of horizontal retorts filled and emptied by hand. In the early days the main thought was the production of gas from the coal, the value and composition of the coke and the by-products being of secondary importance.

In view of the heavy labour required in hand-operated horizontal retorts, attempts were successfully made to set them at such an angle as would allow the coal to flow in and the coke to discharge by gravitation. The development of inclined systems was, however, checked by the application of machines for charging and discharging horizontal retorts. These machines made it possible to work heavier charges of coal in the retorts, with increased output per square foot of ground space, and improved make of gas per ton of coal.

The next development in carbonisation practice was the idea of continuous carbonisation. In this process the coal passes continuously through a vertical retort at a controlled speed, being extracted in the form of coke in a dry cool condition.

Continuous vertical retorts gave the opportunity both of increasing the gas output per square foot of ground space, and of increasing the make of gas per ton of coal carbonised, by steaming the charge of hot coke in the lower parts of the retort. At the same time labour costs were reduced. During the last 15 years, which have seen the establishment of the continuous carbonisation process, there have also been considerable improvements in forms of static processes. Carbonisation of coal in bulk in such types of plant as small coke ovens, intermittent vertical chambers and inclined chambers has met with success. The construction of horizontal retorts has further improved.

In all forms of carbonising plant the improvement in quality of refractory materials has enabled higher carbonising temperatures to be carried, with consequent higher output per square foot of ground space, and per ton of coal treated.

Within the past few years more attention has been paid to the quality of coke produced when carbonising coal on gasworks. The design and operation of modern carbonising plants must take into consideration the efficient production of both gas and coke.

Present-day carbonisation methods.

Carbonisation of coal at gasworks may be discussed under two main headings:—

(1) Static Carbonisation; (2) Continuous Carbonisation.

The chief forms of static carbonisation plants employed are:—

(a) Horizontal Retorts; (b) Inclined Retorts; (c) Intermittent Vertical Chambers; (d) Inclined Chambers; (e) Coke Ovens.

Continuous carbonisation is carried out in continuous vertical retorts.

Each of these forms of plant has its own particular advantage and application. In the development of each form of plant certain factors have been kept in mind.

(1) Labour saving.
(2) High output of gas per sq. ft. of ground space.
(3) High yield of gas per ton of coal.
(4) Low cost of construction.

It has been found possible to develop certain forms of plant to a greater degree than others. Thus, for example, output of gas per sq. ft. of ground space is greater in continuous vertical retorts than with any other form of carbonising plant.

Before discussing in detail each of the above types of carbonising plant, it may be desirable to summarise the requirements of a coal gas plant.

The plant should fulfil the following conditions:—

(a) Low capital cost.
(b) High output per sq. ft. of ground space.
(c) Low labour costs.
(d) Maximum make per ton of coal.
(e) Flexibility of output.
(f) Successful operation on any form of coal.
(g) Low maintenance costs.

The gas made should fulfil the following conditions:—

(a) Constant calorific value; (b) Low volume of inert constituents.

The coke made should fulfil the following conditions:—

(a) Dryness; (b) Minimum of breeze formation.

STATIC CARBONISATION.

Horizontal Retorts. The most important recent developments in horizontal retort practice have been:—

(1) Improved methods of charging and discharging by mechanical means.
(2) Construction of the retorts in silica.
(3) Increase in the length of retorts.
(4) Bigger charges per retort.

These modifications have considerably increased the output per day per retort, and improved the gas-making results per ton.

TABLE I.—CARBONISATION OF COAL, HORIZONTAL RETORTS.

Potential Energy in Coal :	B.Th.U.'s.
1 ton @ 13,400 B.Th.U.'s per lb.	30,016,000
Products of Carbonisation :	
Gas, 13,160 cu. ft. of 545 B.Th.U.'s	7,172,000
Tar, 9.35 galls., @ 185,000 B.Th.U.'s per gall	1,729,750
Coke and breeze, 14.5 cwts., @ 12,284 B.Th.U.'s per lb.	19,950,000
Heat in combustible products, neglecting ammonia, retort carbon, etc.	28,851,750
Thermal efficiency of conversion..96%.	

Products Used on Works in Process :	B.Th.U.'s
Coke for heating retorts, 3 cwt., @ 12,500 B.Th.U.'s per lb.	4,200,000
Breeze for obtaining power, 1 cwt., @ 10,000 B.Th.U.'s per lb.	1,120,000
Total heat used on works	5,320,000
Products for Sale to Public :	
Gas, 13,160 cu. ft. @ 545 B.Th.U.'s	7,172,000
Tar, 9.35 gallons	1,729,750
Coke, 10.25 cwts., @ 12,500 B.Th.U.'s per lb.	14,350,000
Breeze, .25 cwts., @ 10,000 B.Th.U.'s per lb.	280,000
	23,531,750

Commercial Efficiency of Process: 78.4%.

NOTE.—If all power is derived from waste heat steam, then 1¼ cwts. of breeze are for sale, and the efficiency becomes 82.5 per cent.

Mr. T. Hardie, Chief Engineer of the Gas Light & Coke Co., Ltd., has described a modern installation of horizontal retorts at Beckton Works in a paper before the Institution of Fuel Technology.* This paper† is somewhat freely quoted in the present section because it is felt that, in a volume on Britain's fuel problems, no sounder basis could be taken concerning modern gasworks practice than Mr. Hardie's carefully presented observations dealing with the largest gas undertaking in the world.

Figure No. 1 shows a cross section of a modern setting of horizontal retorts comprising 10 retorts set in two vertical rows of 5 tiers. In the retort house there are three benches each containing nine settings. The retorts are charged with coal every 12 hours. The weight per charge is 17 cwts., or 34 cwts. of coal per 24 hours. The retorts are heated by means of an internal producer situated at the base of each setting. To this producer is fed hot coke direct from the retorts. The fuel consumption is approxi-

* Now The Institute of Fuel. † Hardie "Some Phases of Modern Gas Manufacture," *The Fuel Economist*, Dec., 1926.

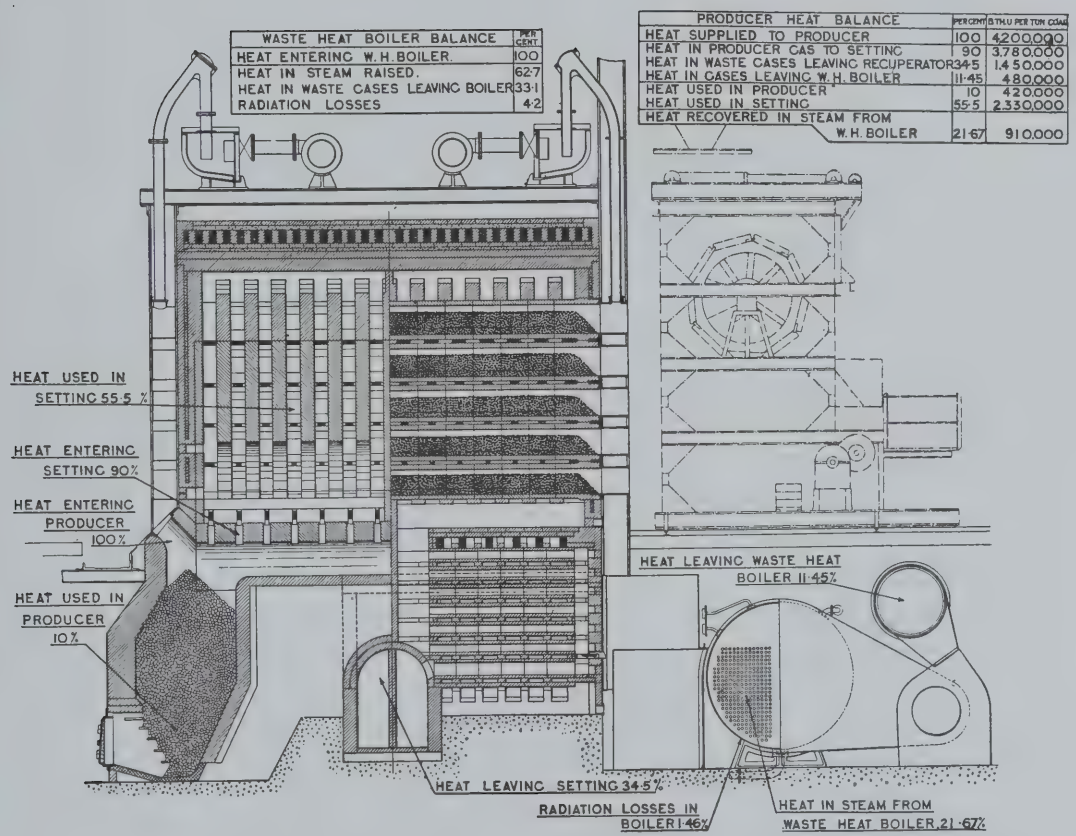

WASTE HEAT BOILER BALANCE | PER CENT
HEAT ENTERING W.H. BOILER. | 100
HEAT IN STEAM RAISED. | 62·7
HEAT IN WASTE CASES LEAVING BOILER | 33·1
RADIATION LOSSES | 4·2
PRODUCER HEAT BALANCE | PER CENT | B.T.H.U. PER TON COAL
HEAT SUPPLIED TO PRODUCER | 100 | 4,200,000
HEAT IN PRODUCER GAS TO SETTING | 90 | 3,780,000
HEAT IN WASTE CASES LEAVING RECUPERATOR | 34·5 | 1,450,000
HEAT IN CASES LEAVING W.H. BOILER | 11·45 | 480,000
HEAT USED IN PRODUCER | 10 | 420,000
HEAT USED IN SETTING | 55·5 | 2,330,000
HEAT RECOVERED IN STEAM FROM W.H. BOILER | 21·67 | 910,000
HEAT USED IN SETTING 55·5 %
HEAT ENTERING SETTING 90%
HEAT ENTERING PRODUCER 100%
HEAT USED IN PRODUCER 10%
HEAT LEAVING WASTE HEAT BOILER 11·45%
HEAT LEAVING SETTING 34·5%
RADIATION LOSSES IN BOILER 1·46%
HEAT IN STEAM FROM WASTE HEAT BOILER, 21·67%

FIG. 1.

Shewing Waste Heat and Waste Heat Boiler Balance.

mately 3 cwts. of coke per ton of coal carbonised. Producer gas enters the combustion chamber through 14 nostrils arranged along the length of the retorts in an arch, which forms, in part, the crown of the producer. At each side of these nostrils are pairs of secondary air ports, and combustion takes place at these points, the hot gases passing upwards, centrally, between the two vertical rows of retorts, dividing at the top and passing downwards along the outsides of the retorts. They then enter the secondary air recuperators which are placed on either side of the producer between it and the main walls of the setting. The gases are then drawn through a waste heat boiler and pass back to the stack for discharge. The recuperators are formed of thin fireclay tubes through which waste gases pass, the secondary air passing around the outside of the tubes.

The setting is insulated by building a course of diatomaceous bricks in the front and back walls, and by building into the crown of the setting two courses between which are arranged a diagonal series of bricks on edge, forming a cellular air blanket.

On Figure 1 will be noted the producer heat balance and waste heat boiler balance for a modern horizontal retort setting.

Table I. gives a thermal balance sheet for carbonisation of coal in horizontal retorts. It will be seen that the thermal efficiency of conversion of coal into its carbonisation products gas, tar, coke, is 96 per cent. A certain amount of fuel is required for heating the retorts and for supplying power to operate the plant. If this fuel be deducted, a figure, termed by Hardie as the " commercial " efficiency of the process, can be derived. This with horizontal retorts works out at 78.4 per cent.

Intermittent Vertical Chambers. Another form of static carbonisation plant is the intermittent vertical chamber, which is a development of the Dessau intermittent system. In the intermittent vertical chamber the space formerly occupied by 2 or 3 retorts is now occupied by one large chamber. Figure 2 shows a diagrammatic cross section through the plant. Coal is elevated to the overhead hoppers. From these hoppers a charge of coal falls into a hand-propelled charging skip. When a chamber is to be charged, the bottom door is tightened and a pad of breeze allowed to fall into the chamber from a special compartment in the coal-charging skip. The coal is then dropped into the chamber. When carbonisation is completed the charge is removed by opening the bottom door, which is hydraulically operated. During the last two hours the charge in the chamber may be steamed, which results in an increased thermal yield per ton of coal.

An installation of intermittent vertical chambers consists of a number of settings, each containing 2, 3, 4, 5 or 6 chambers, a producer, a recuperator and waste gas flue.

In the installation at Ramsgate, built by the Woodall-Duckham Company, the chambers each hold 2.25 tons of coal which, with a coking time of 12 hours, gives a throughput of 4.5 tons per chamber per day. The chamber faces and combustion chambers are constructed in best quality silica material for a depth of approximately 14ft. 4in. The chambers have a special ovate cross section, the minor axis tapering slightly towards the two ends which are semi-circular in shape. The settings are heated by producer gas which is made in step grate producers. The combustion chambers are horizontal. The top of the setting and the front walls are insulated to reduce heat losses.

In addition to the fact that intermittent vertical chambers occupy a small amount of ground space, they have the advantage that a larger gas yield can be obtained per ton of coal carbonised than with horizontal retorts, due to the steaming of the charge during the last two hours of the carbonising period. This form of plant is suitable for carbonising any class of coal or slack, including the coals of the Kent coalfield, producing a coke somewhat similar to horizontal retort coke.

Inclined Chambers. The inclined chamber is a development of the inclined retort. In modern gasworks practice there is a tendency to adopt bulk methods of carbonisation. The inclined chambers are designed to carbonise charges of from 3 to 5 tons, and successful results are obtained using any variety or size of coal. Figure 3 shows a section through a chamber. From the overhead bunker coal is fed through a hopper into the inclined chamber. The chamber is heated by producer gas generated in a built-in producer. When the coal is carbonised the bottom door is raised, and the coke falls out into a quenching car. Occasionally it is necessary to start the charge of coke sliding, and for this purpose a small pusher is provided.

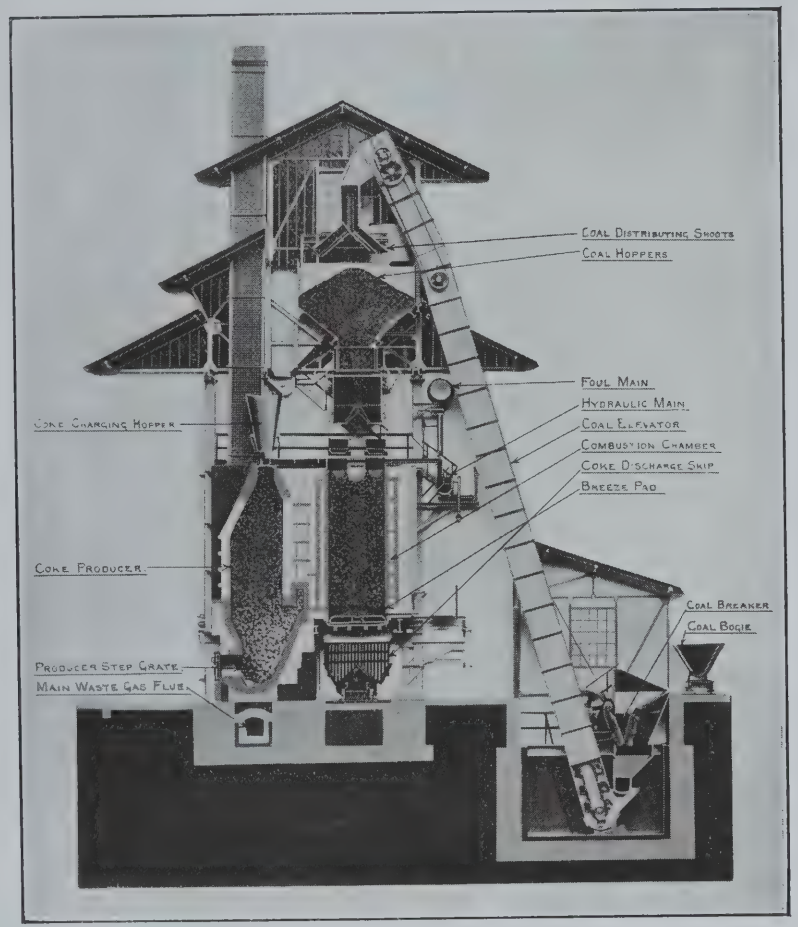


FIG. 2.

Intermittent Vertical Chamber.
Diagrammatic Cross-section through Plant.

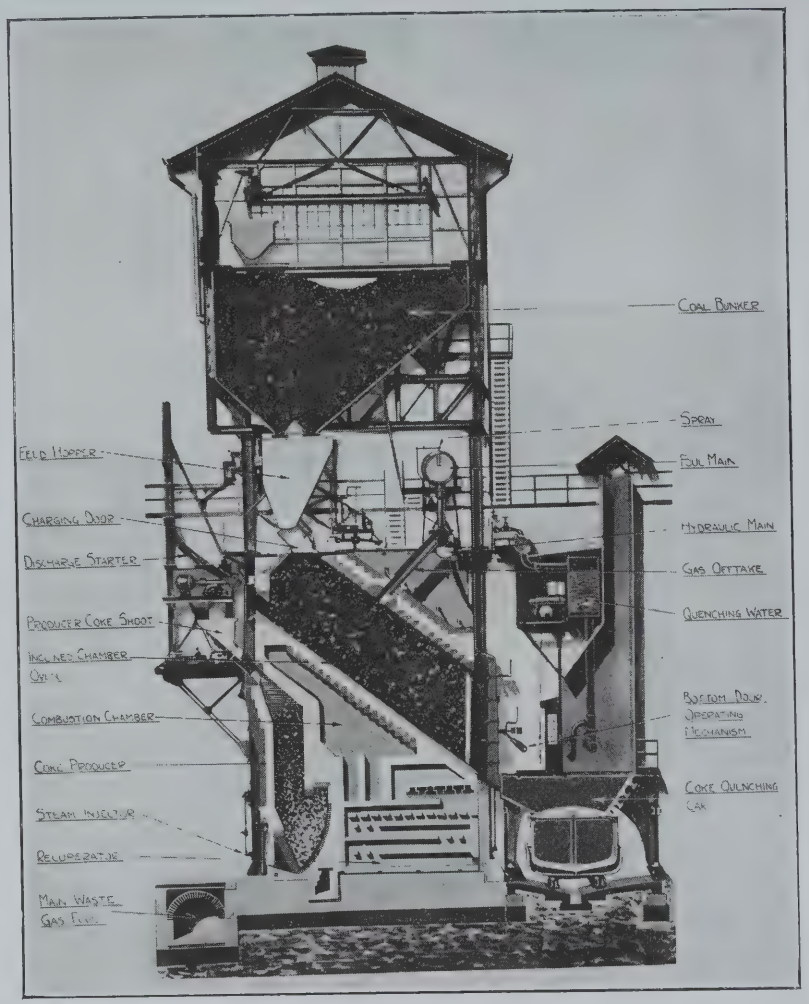


FIG. 3.

Inclined Chamber.—Section through Chamber.

The make of gas from inclined chambers is at least equal to the best horizontal practice, and in addition the chambers can be steamed during the last hour or two of the carbonising period. The ground space required is low.

Coke Ovens. Up to a comparatively short time ago coke ovens were considered unsuitable for gasworks, but in the last few years various ovens have been developed which are specially designed for gasworks purposes. G. M. Gill* has recently described a number of such ovens. Small oven installations, he considers, are not justified for plants to make less than 300,000 cu. ft. per day. They are made of various sizes with a coal capacity of 2,500-4,000 lbs., and with a carbonising period of 12 hours. The usual form of setting consists of three ovens and one producer, giving a carbonisation capacity equal to a horizontal setting of eight through retorts. The oven is charged through two openings in the top, and the coke is discharged by a pushing machine fitted also with an apparatus for levelling the charge. The coke is pushed out into a travelling coke wagon in which it is quenched by water.

For small works the ovens are now being built as separate units. Each unit consists of one oven and one recuperator, the oven being heated by producers common to all the ovens. Typical particulars of one of these small ovens are given by Gill as follows:—Size (internal), 12ft. long by 6ft. high by 12in. wide (parallel). Coke space, 10ft. long by 5ft. high by 12in. wide. Carbonising period, 12 hours. Weight of charge at 50 lbs. per cu. ft., 2,500 lbs.

Ovens, however small, require the use of a coke pusher, a coal truck, and a coke wagon, all mechanically operated, and there is thus a distinct limit to the size of plant. This, as already stated, Gill places at ten small ovens, or 300,000 cubic feet per day.

In America a great deal of attention has been paid to the development of ovens suitable for gasworks purposes. In order to attain this the Koppers Company of America introduced flexibility in gas production by the provision of mechanical producers and divided regenerators for preheating both producer gas and air, to enable either producer gas or coal gas to be used for heating the ovens. The modern narrow ovens hold many advantages over the old ovens, such as:—(1) High speed of carbonisation and high output per square foot of ground space; (2) Uniform quality of coke; (3) Low fuel costs; (4) High production of gas, tar and ammonia.

CONTINUOUS CARBONISATION.

Continuous Vertical Retorts. The progress and development of continuous vertical retorts have been among the outstanding features in gasworks engineering during the past 20 years, and to-day over 50 per cent. of the coal carbonised in Great Britain is treated in continuous vertical retorts.

The early attractions of the process were the small amount of ground space and the low labour costs, coupled with comfortable operating conditions, but in recent years with the general adoption in the gas industry of the calorific value basis in place of the illuminating power standard, continuous vertical retorts have proved to have the additional advantage of giving a higher gas output per ton of coal than can be obtained with any other form of carbonising plant. This is due to the fact that steam can be introduced at the bottom of the vertical retort, producing, as the result of interaction with red-hot coke, blue water-gas of good quality, which mixes with the coal gas and thus increases the make per ton.

The two leading systems of continuous vertical retorts are:—

(a) The Woodall-Duckham System; (b) The Glover-West System.

The main principle of the Woodall-Duckham system is the regulated continuous descent of the coal through a suitably constructed and heated vertical retort. The speed of descent is so regulated that the coal entering at the top is gradually carbonised in its passage through the retort, and converted into coke by the time it arrives at the bottom. The various gases and by-products ascend and are taken away from the top of the retort.

Figure 4 gives a cross section of a Woodall-Duckham vertical retort. Coal is elevated to the overhead coal hopper. From this hopper coal is allowed to fall at intervals through a gas-tight coal valve into the auxiliary coal hopper, which is connected to the retort mouthpiece. This auxiliary hopper holds approximately 2 hours' supply of coal. The rate of travel of coal into the retort is governed by the rate

*Ovens as a Gas Works Carbonising Plant. Inst. Gas Engineers, 1927.

of extraction of coke by means of the coke extractor situated at the bottom of the retort. The W.-D. coke extractor consists of a roller with a series of cast-iron cross-pieces threaded radially on a square shaft, each cross-piece having a slight lead on its neighbour, so that in effect, a helix is formed. This construction ensures that the discharge of the coke is the same throughout the whole revolution of the extractor roller, and therefore the travel of the charge through the retort is constant.

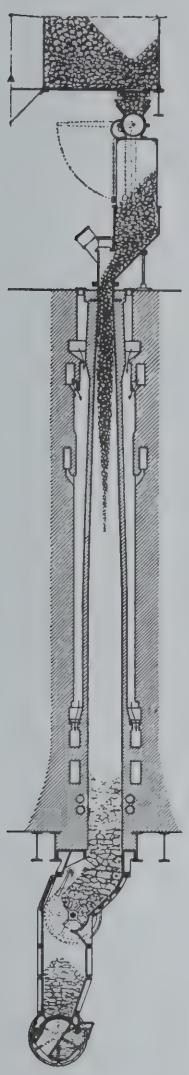


FIG. 4.—*Woodall-Duckham Vertical Retort. Cross-section through Minor Axis.*

The whole of the combustion flues, including the retort faces, are constructed of high quality silica material. The heating flues are vertical. Producer gas and secondary air are brought to the top of the setting and the combustion of the gases proceeds downwards. Arrangements are made so that a proportion of the secondary air can be introduced at a lower level.

Below the coke extractor is fitted a cast-iron receiving hopper, which is constructed to contain 2 hours' discharge of coke. The coke hopper is closed by a water-sealed door.

Arrangements are made to use the heat of the coke for the production of water gas by admitting steam through suitable jets fitted into the curved plate of the coke extractor box. The amount of steam introduced into the retort depends upon the class of coal to be carbonised and the calorific value of the gas required.

The retorts are made in different carbonising capacities. The minor axis dimensions are kept constant, variation in carbonising capacity being obtained by increasing or decreasing the major axis length. The standard minor axis dimensions are 10in. at the top, 18in. at the bottom. The major axis dimensions of retorts, already built vary from 50in. to 103in. The carbonising capacities of the retorts vary from 4 to 10 tons per 24 hours.

Figure 5 shows one of the latest designs of Woodall-Duckham continuous vertical retort plants erected at the Bow Common Station of the Gas Light and Coke Co., London (Hardie, Inst. Fuel Technology). This installation consists of two benches each containing 34 vertical retorts. Each retort will carbonise $7\frac{1}{2}$ to 8 tons of coal per day. Each bench of retorts is heated by a battery of 5 outside producers burning coke. The producer gas is taken from the producers by a distributing main to the top of vertical flues at the sides of the retorts. At the base of the retorts the waste gases are collected and discharged to the stack. The secondary air circulates around the base of the retorts before rising to the combustion zone through the flues, but is otherwise not heated. Steam for gasification and coke cooling is admitted to the coke extractor chambers. The whole of the setting exterior is cased in insulating bricks and hollow bricks, packed with slag wool. The waste gas mains and producer gas mains are brick lined and lagged. Figure 5 also shows the figures for the producer heat balance and waste heat boiler balance.

The Glover-West system.

The main principles of the Glover-West system are similar to the Woodall-Duckham system, but it has a number of distinctive features.

The retorts are elliptical in cross section. In one model the retort expands from 40in. by 10in. at the top to 46in. by 18in. at a depth of 21ft. In another mode the dimensions increase from 33in. by 10in. at the top to 39in. by 18in. at the 21-ft. level. Immediately below the retort is a steaming chamber, 4ft. in depth, in which the dimensions increase more rapidly to 40in. on the minor axis. The object of this steaming chamber is to increase the surface of coke exposed to the action of steam for the production of water gas. The coke is extracted by means of a spiral extractor into a cooling chamber below the retort.

Figure 6 shows a cross section through the minor axis of a Glover-West retort. Coal passes from an overhead storage bunker through a coal valve into the auxiliary hopper, and thence into the retort,

the rate of travel through the retort being governed by the rate of extraction of coke by the spiral extractor at the bottom of the retort. The retorts are heated by the combustion of producer gas.

The producers are at the base of each setting and supply gas to several super-imposed horizontal chambers for heating the retorts, which are surrounded by the latter. The admission of producer-gas and secondary-air to each chamber is separately controlled, so that the distribution of temperature throughout the vertical length of the retort can be adjusted to suit the requirements of the coal under treatment. When a high proportion of steam is admitted to the retort the temperature is greater near the base. The steam is required for the production of water-gas and cooling the coke.

Some coals require a higher temperature in the upper portion of the retort, others an equal temperature throughout the length of the retort. The secondary-air rises in the back wall of the setting adjacent to the internal waste-gas uptake, fulfilling the double purpose of regeneration and insulation. The setting is protected from loss of heat by insulating bricks. Waste gases pass upwards through the chambers of the setting into circulating flues round the upper portions of the retort, thence through collecting flues (lined with insulating bricks) to waste-heat boilers and the atmosphere. The producers have no grate doors, the ingress of air being automatically controlled by the main draught through the settings.

Waste Heat Boiler Balance.	
Heat Entering Waste Heat Boiler	100%
Heat in Steam Raised	74%
Heat in Waste Gases leaving Boiler	21%
Radiation Losses	5%

Producer Heat Balance.		B.T.U. per Ton Coal.
Heat Supplied to Producers	100%	3,668,000
Heat in Producer Gas to Setting	88%	3,227,840
Heat in Waste Gases leaving Setting	57%	2,090,000
Heat in Waste Gases leaving Waste Heat Boiler	12.3%	450,000
Heat Used in Producer ..	12%	440,160
Heat Used in Setting ..	31%	1,137,840
Heat Recovered in Steam from Waste Heat Boiler..	42.0%	1,540,000

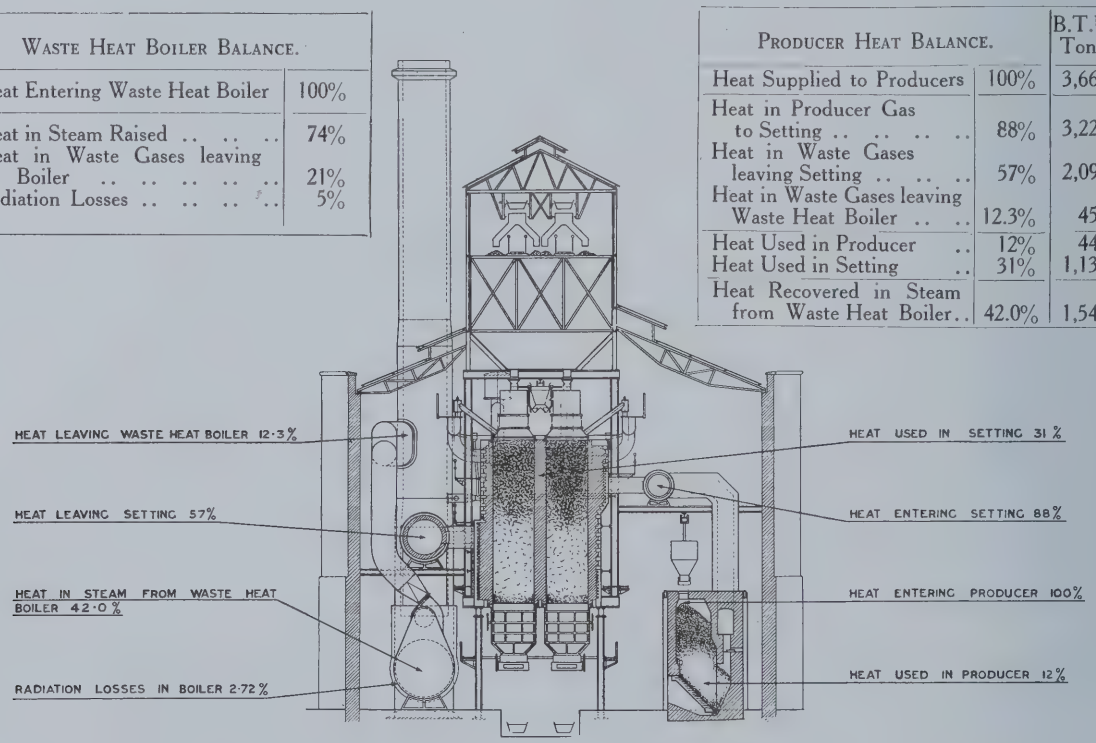
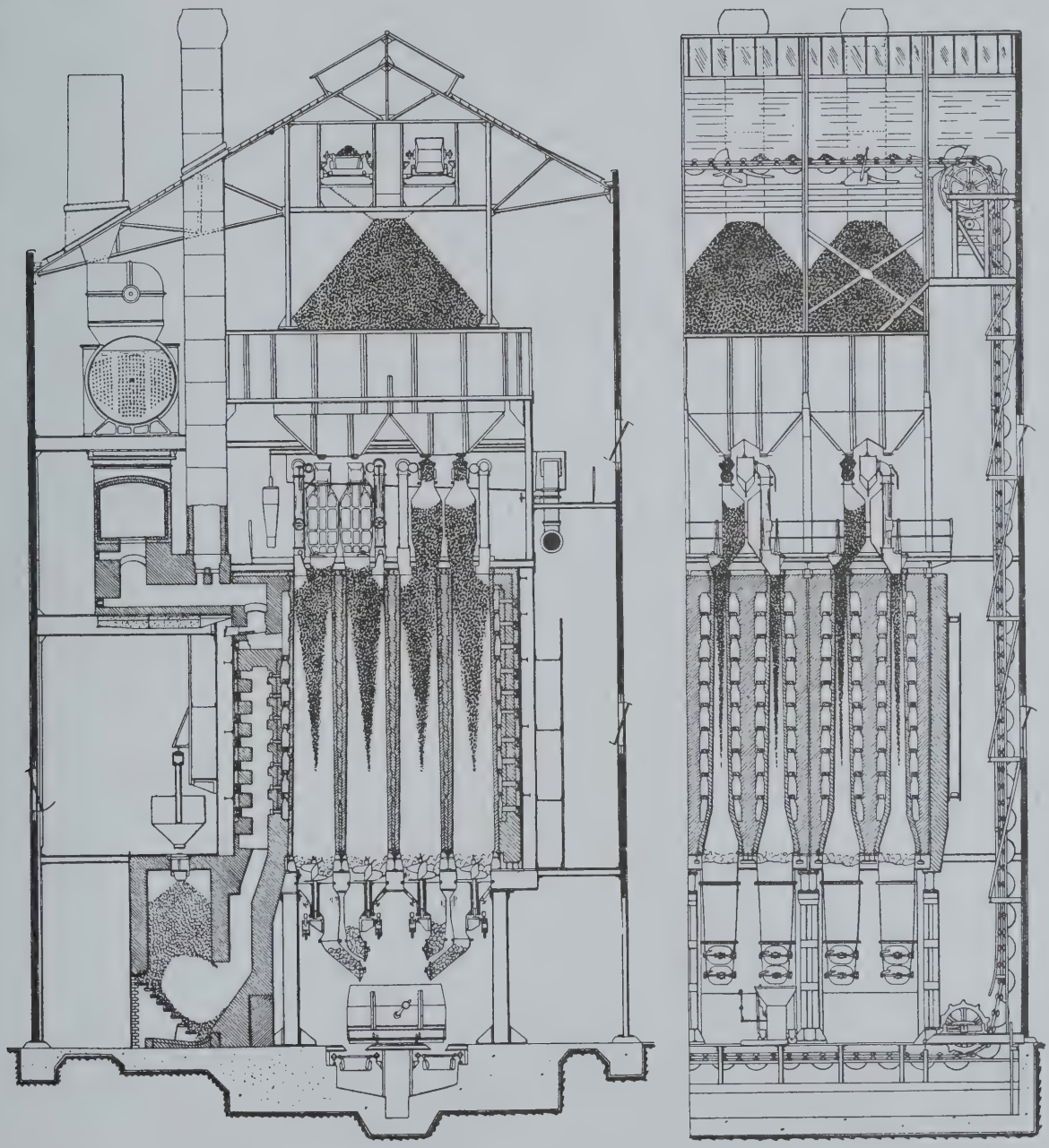

HEAT LEAVING WASTE HEAT BOILER 12·3%
HEAT LEAVING SETTING 57%
HEAT IN STEAM FROM WASTE HEAT BOILER 42·0%
RADIATION LOSSES IN BOILER 2·72%
HEAT USED IN SETTING 31%
HEAT ENTERING SETTING 88%
HEAT ENTERING PRODUCER 100%
HEAT USED IN PRODUCER 12%

Fig. 5.—*Carbonising Plant at the Gas, Light and Coke Co.'s Bow Common Station* (Hardie).

Figure 7 shows a recent installation of the Glover-West system of continuous vertical retorts erected at the Nine Elms Station of the Gas Light and Coke Co., London. It consists of a bench of 14 settings, each setting containing 8 retorts. Each retort carbonises 4.75 tons of coal per 24 hours.

The efficiency of vertical retort carbonisation.

Table II. gives a thermal balance sheet for the carbonisation of coal in continuous vertical retorts. This should be compared with Table I. for horizontal retorts. It will be seen that the efficiency of conversion of coal into its products is 95.84 per cent., whilst the commercial efficiency is 85.6 per cent.



Cross Section.

Part Longitudinal Section.

FIG. 7.

Installation of Glover-West Continuous Vertical Retorts at the Nine Elms Station of the Gas Light and Coke Co. Ltd.

FACTORS INFLUENCING CHOICE OF CARBONISING PLANT.

Although at the present time there is a steady increase in the number of installations of inclined chambers, intermittent vertical chambers, and coke ovens for gas works, it may be stated, on a conservative estimate, that over 98 per cent. of the coal carbonised in gas works is treated in either continuous vertical retorts or in horizontal or inclined retorts. The modern continuous vertical retort and the modern machine-charged horizontal retort represent the two forms of gas-making plant most in use to-day.

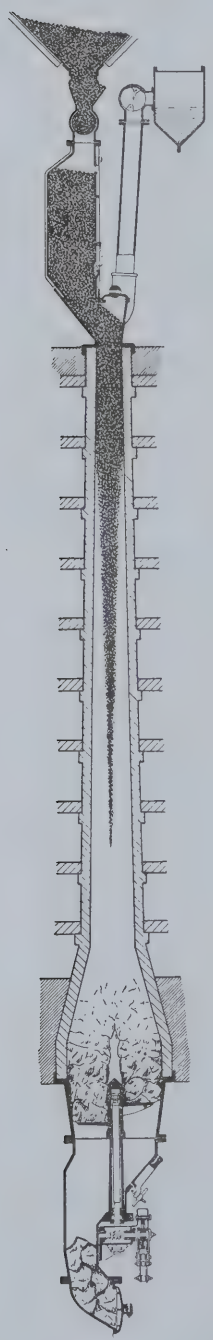


FIG. 6.

In determining the most suitable plant for any works a number of factors must be considered. T. Carmichael in a recent paper,* points out that local markets and circumstances vary so greatly that the particular processes and grade of gas most suitable for one undertaking might be very different from those which would rightly be chosen in other circumstances. In deciding the most suitable plant to install a gas engineer must consider :—

(1) The class of suitable coal which, owing to local circumstances and geographical position, is most easily and cheaply obtained.
(2) The calorific value of the gas to be made.
(3) Ground space to be occupied.
(4) Carbonising wages.
(5) Fuel costs.
(6) Capital costs.
(7) Total cost of gas production.

Upon some of these points useful information has recently been published, and may be summarised as follows :—

Range of Calorific Value. The various forms of carbonising plant differ in the range of calorific value of gas that can be made in them. The widest range is found with continuous vertical retorts, due to the fact that continuous steaming of the charge is possible with the production of blue water-gas. Table III. shows the approximate range of calorific value with various forms of carbonising plant.

Order of Flexibility in Calorific Value. (1) Continuous vertical retorts ; (2) Intermittent vertical chambers ; (3) Inclined chambers ; (4) Horizontal retorts ; (5) Coke ovens.

Ground Space Occupied. Table IV. shows the comparative results and ground space occupied by modern plants of the Gas Light and Coke Co.† It will be seen that the therms of gas made per 24 hours per sq. ft. of site is 1.48 with modern horizontals, and 2.71 with continuous verticals. With still more recent continuous vertical retort installations the output is approximately 3.0 therms per sq. ft. per 24 hours.

Output of gas per square foot of ground space is a factor of great importance, especially to undertakings whose manufacturing stations are situated in congested areas.

Carbonising Wages. Table V. shows the carbonising wages on various forms of plant. The wages cost per ton of coal carbonised is practically the same with modern horizontal retorts and continuous vertical retorts. If, however, the fact that the continuous vertical retorts give a higher thermal yield be taken into consideration, the labour cost per therm is slightly in favour of continuous vertical retorts.

Fuel Costs. In modern installations of horizontal retorts and continuous vertical retorts, waste heat boilers are usually installed to recover the heat from the waste gases leaving the setting. This has led to the conception that as regards fuel costs the important thing is the nett fuel cost, namely, the heat supplied to the producer less the heat value of steam recovered.

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* Modern Carbonising Economics. Inst. Gas Engineers, 1927.
† T. Hardie.—Presidential Address, Southern Association Gas Engineers and Managers, March 30th, 1927.

Making a comparison between his figures for horizontal and continuous vertical retorts, T. Hardie sets out his producer balance for these two plants in Table VI.

This difference is accounted for by

(1) The lower temperature of the coke discharge—1,350° F. lower.
(2) The reduced temperature of the volatile products leaving the retorts—200° F. lower.
(3) The reduced radiation from the bench, in consequence of the smaller surface area for a given throughput capacity of plant.

Assuming that the calorific value of dry coke is 12,500 B.Th.U.'s per lb., and defining nett fuel consumption as the heat supplied to producer, less the heat value of steam recovered, the figures become

NETT FUEL CONSUMPTION

Horizontal retort	.. ..	=	11.75 lbs. dry coke per 100 lbs. coal.
Continuous vertical retorts	..	=	7.6 „ „ „

Gas Works Construction Costs.—During the past few years improvements in design have led to considerable reduction in carbonising plant construction costs. From their experience in carrying out a number of reconstruction schemes the Gas Light and Coke Co., London, have been able to compile average costs representative of present-day practice. Table VII. shows these figures (Hardie)*, which are definitely applicable to extensions of from 5 to 7 million cubic feet per day but may be taken as average figures.

Cost of Gas Production.—In determining the comparative value between various forms of a carbonising plant, the cost of gas production is naturally one of the most important. The complete cost of gas production must include: (1) carbonisation cost; (2) maintenance charges; and (3) capital charges.

Costs of production vary widely between various gas undertakings, but certain general statements may be made:—

(1) The predominant factor in gas production cost is the nett coal figure, namely, coal on works less residuals. This involves two considerations, firstly, to take advantage of the cheapest suitable coal, and secondly, to obtain the maximum credit from the residuals by the suitable preparation of the coke, tar, and ammonia.

(2) The cheapest gas is not necessarily made by the biggest undertakings. Highly efficient plants can be obtained suitable for small undertakings, so designed and operated as to give low costs of production.

As an indication of modern carbonising economics, T. Carmichael† has recently presented the results of his own experiences with modern horizontal retorts and continuous vertical retorts. Table VIII. shows the cost of gas production (carbonising only) and Table IX. the final comparative cost of gas production, including maintenance and capital charges. The figures are expressed per ton of coal, per 1,000 cubic feet, and per therm. In each case the coal is charged at the same figure, but in the case of the vertical retorts the coal is from stock, whereas in the case of the horizontal retorts the coal is fresh, unscreened, Durham coal. Expressed as percentages, the total cost of gas production is made up of the items (based on Carmichael's figures) given in Table X.

The gas industry is the public service with the largest consumption of coal, and in this chapter an attempt has been made to show that, by the collective effort of gas engineers and gas plant designers, the industry treats coal scientifically and economically.

From every ton of coal carbonised on modern gas works the community receives products in the form of gas, coke and tar, representing over 80 per cent. of the thermal value of the coal, an efficiency not approached by any other form of conversion of coal into light, heat, fuel and power.

*Presidential Address, Southern Association Gas Engineers and Managers, March, 1927.
†Modern Carbonising Economics.—T. Carmichael, Institute of Gas Engineers, 1927.

TABLE II.—CARBONISATION OF COAL IN CONTINUOUS VERTICAL RETORTS EQUIPPED WITH WASTE HEAT RECOVERY.

	B.Th.U.'s.
Potential Energy in Coal:	
1 ton @ 13,400 B.Th.U.'s per lb. =	30,016,000
Products of Carbonisation:	
Gas, 15,300 cu. ft. of 510 B.Th.U.'s cu. ft.	7,803,000
Tar, 11 galls. @ 18,181,810 B.Th.U.'s per gall	2,000,000
Coke and breeze, 13.83 cwts., @ 12,242 B.Th.U.'s per lb.	18,964,400
Heat in combustible products	28,767,400
Thermal efficiency of conversion	95.84%
Products Used on Works in Process:	
Coke for heating retorts, 2.62 cwts., @ 12,500 B.Th.U.'s per lb.	3,668,000
All power from waste heat steam, and similarly steam to retorts.	

Products for Disposal to Public:	B.Th.U.'s.
Gas, 15,300 cu. ft., @ 510 B.Th.U.'s	7,803,000
Tar, 11 gallons	2,000,000
Coke, 9.79 cwts., @ 12,500 B.Th.U.'s per lb.	13,706,000
Breeze, 1.42 cwts., @ 10,000 B.Th.U.'s per lb.	1,590,400
Steam, surplus for other purposes not required for power or gas production	596,000
	25,695,400
Commercial Efficiency of Process:	85.6%

TABLE III.—RANGE OF CALORIFIC VALUE.

(Without excessive percentage inerts—less than 15 per cent.)

	Highest.	Lowest.	Range.
Horizontal retorts	600 B.Th.U.'s	500 B.Th.U.'s	100 B.Th.U.'s
Intermittent vertical chambers	600 „	475 „	125 „
Inclined chambers	600 „	485 „	115 „
Coke ovens	590 „	525 „	65 „
Continuous verticals	560 „	400 „	160 „

TABLE IV.

Type of Plant.	Inclined.	Horizontal.	Continuous Verticals.
Size of retort-house required	310ft. by 63ft.	360ft. by 65ft.	192ft. by 60ft.
Number of retorts	240	270	128
Size of retorts	24in. by 14in. by 20ft.	24in. by 18in. by 23ft.	33in. by 10in. at top to 39in. by 25in. at bottom
Power	Steam	Electric	Electric
Coal	Midland	Durham	Durham
Coal per month (average)	9,200 tons	14,400 tons	12,400 tons
Coal per full day	306 „	480 „	400 „
Charge per retort	9.2 cwts.	19.5 cwts.	3.4 tons per day
Duration	8.5 hours	12.0 hours	—
Coal per retort (working) per day	1.3 tons	1.95 tons	3.4 tons
Therms per retort (working) per day	94.9	140.4	265.2
Therms per ton	73	72	78
Therms per day	22,338	34,560	31,200
Cu. ft. per day	4,150,000	6,250,000	6,120,000
Average of retorts	235	246	117
Average of site sq. ft. gas making	19,500	23,400	11,520
Cu. ft. of gas made per 24 hours per sq. ft. of site	212.8	267.1	531.2
Therms of gas made per 24 hours per sq. ft. of site	1.15	1.48	2.71

TABLE V.—CARBONISING WAGES ON VARIOUS FORMS OF PLANT.

	Price per Ton of Coal. Inclined Retorts.	Horizontal Retorts.	Continuous Verticals.
Coal (from delivery to crushers to bunkers) ..	1.75	0.54	0.42
Carbonising (coal from bunkers to coke to conveyors and furnaces)	23.79	11.12	11.18
Coke (coke from retort house to storage in bunkers)	16.00	0.93	1.4
Incidentals (foreman, lobbies, etc.)	3.54	3.31	3.29
Total Wages	45.08	15.90	15.93

TABLE VI.—PRODUCER HEAT BALANCE.

	Horizontal System. B.Th.U.'s.	Continuous Vertical System. B.Th.U.'s.
Supplied to producer	4,200,000	3,668,000
Passing up stack	480,000	450,000
Used and lost in producer, carbonising plant, etc., and recovered in boilers	3,720,000	3,218,000
Heat value of steam recovered..	910,000	1,540,000
Used and lost in carbonising and producer plant	2,810,000	1,678,000

Difference in favour of vertical retorts—1,132,000 units.

TABLE VII.—GAS WORKS CONSTRUCTION COSTS.

(Including Foundations, Contract and Direct Labour and Connections).

	Per million cu. ft. per day. £	Per ton of coal per day. £		Per million cu. ft. per day. £	Per ton of coal per day. £
Carbonising plant and waste-heat boiler ...	16,100	249.6	Coal handling and storage plant	1,420	22.0
Condensers	1,290	20.0	Coke handling plant ...	1,620	25.1
Exhausters	650	10.1	Mains, services and cables	2,600	40.3
Livesey washers ...	190	2.9	Tar and liquor storage ...	1,300	20.2
Ammonia washers ...	1,050	16.3	Ash handling plant ...	840	13.0
Naphthalene washers ...	520	8.1	Gasholders (12 hours' make)	9,300	144.2
Purifiers with oxide handling plant ...	5,100	79.0			
Station meters	900	13.9			
Electric power plant ...	1,300	20.2		£45,880	£711.3
Coal unloading plant ...	1,700	26.4			

TABLE VIII.—COST OF GAS PRODUCTION (Carbonising only).

TYPE OF COAL	Continuous Vertical Retorts. Modern Silica Setting. Durham (Stock)	Horizontal Retorts. Modern Setting. Durham (Unscreened).
Coal carbonised, tons, 24 hours	129.6	95.4
Gas made per 24 hours, cu. ft.*	1,888,000	1,221,000
Gas made per ton, cu. ft.*	14,570	12,800
Calorific value, gross ...	477.5	523.5
Therms per 24 hours ...	9,017	6,392
Therms per ton of raw coal	69.6	67.0
Number of men per 24 hours	17	24
Labour cost per 24 hours	£8 15 6	£12 6 2
Therms per man—day	530	266
Cost of labour:		
Per ton ... s. d.	1 4.2	2 7.0
Per 1,000 cu. ft. d.	1.11	2.42
Per therm ... d.	0.23	0.46
Cost of coal per ton s. d.	25 3	25 3
Value of residuals per ton of coal with coke at 30s. per ton s. d.	19 3	19 3
Nett cost of materials:		
Per ton s. d.	6 0	6 0
Per 1,000 cu. ft. d.	4.94	5.63
Per therm ... d.	1.03	1.08
Total cost:		
Per ton ... s. d.	7 4.2	8 7.0
Per 1,000 cu. ft. d.	6.05	8.0
Per therm ... d.	1.26	1.54
Per therm, less credit for surplus steam d.	1.25	1.41

*Corrected to 60° Fahr. and 30in. (moist).

TABLE IX.—FINAL COMPARATIVE COST GAS PRODUCTION BASED ON TABLE VIII.

TYPE OF COAL	Continuous Vertical Retorts. Modern Silica Setting Durham (Stock)	Horizontal Retorts. Modern Setting. Durham† (Unscreened).
Per ton:		
Nett coal ... s. d.	6 0	6 0
Labour ... ... s. d.	1 4.2	2 6.4
Total cost of production s. d.	7 4.2	8 6.4
Maintenance ... d.	11.2	9.7
Capital charges s. d.	1 5.7	1 2.7
Total ... s. d.	9 9.1	10 6.8
Per 1,000 cu. ft.:		
Nett materials d.	4.94	5.34
Labour ... d.	1.11	2.25
Total cost of production d.	6.05	7.59
Maintenance ... d.	0.77	0.73
Capital charges d.	1.22	1.09
Total ... d.	8.04	9.41
Per therm :		
Nett materials d.	1.03	1.03
Labour ... d.	0.23	0.43
Total cost of production d.	1.26	1.46
Maintenance ... d.	0.16	0.14
Capital Charges d.	0.26	0.21
Total ... d.	1.68	1.81
Credit for surplus steam d.	0.01	0.12
Nett Total Cost ...	1.67	1.69

TABLE X.

	Continuous Vertical Retorts.	Horizontal Retorts.
Nett Coal	62%	57%
Labour	14%	24%
Maintenance	10%	8%
Capital Charges	14%	11%
	100%	100%

Chapter 2.

COAL-GAS BY-PRODUCTS AND THEIR UTILISATION.

By T. F. E. Rhead, M.Sc., F.I.C.

The nature and possibilities of the multitude of substances into which bituminous coal can be resolved by heat are being realised more and more as time goes on.

In this way coal has become the starting point of an enormous number of products of incalculable importance to humanity, and, in consequence, economists have been forced to the conclusion that the best way of utilising our chief national asset is, not to burn it in the raw state, but to subject it to a preliminary heat treatment, during which it is split up into fuels (coke and coal gas) and other valuable by-products.

The gas industry is daily carrying out the treatment of coal in this economic and scientific manner.

RECOVERY OF BY-PRODUCTS.

During the distillation of bituminous coal in retorts of highly refractory material, in accordance with gasworks' practice, hot crude gas is evolved containing tarry and aqueous vapours, together with various gaseous impurities, such as sulphuretted hydrogen, ammonia, hydrocyanic acid and hydrochloric acid.

Coke.—A carbonaceous residue of coke equal to 60 to 70 per cent. of the coal remains in the retort.

Tar and Liquor.—In the subsequent cooling and scrubbing operations the by-products, tar, and ammoniacal liquor, are obtained.

Sulphur.—The gas is then passed through purifier boxes containing layers of suitable oxide of iron to purify it from sulphuretted hydrogen (a harmful impurity which by legal enactment must be removed before the gas can be sold to the public). The oxide in time becomes "spent," and then contains about 50 per cent. of sulphur—constituting the by-product "spent oxide," which finds a ready use as home-produced sulphur for the manufacture of sulphuric acid.

Cyanide Recovery.—In the past, it has paid on large works to extract separately hydrocyanic acid from the gas—the resulting by-products being sodium ferro-cyanide (prussiate of soda), or ammonium sulpho-cyanide. Sodium cyanide manufactured from these products is used extensively in gold extraction operations. Cyanides are also used to a minor extent in many other industries. Where special extraction from the gas is not practised about 20 per cent. goes into the liquor, 60 to 70 per cent. into the oxide, and the remainder into the purified gas.

From the engineer's point of view hydrocyanic acid is an undesirable impurity because it causes (1) difficulties in "working up" of ammoniacal liquor; (2) reduction in the efficiency of the oxide in the purifiers, and (3) corrosion in mains, services and meters. *Cyanide recovery has practically ceased to pay, presumably owing to the limited demand and competition of synthetic cyanide. Because of the above troubles, however, many engineers consider it should be removed whether directly profitable or not.

Crude Benzol.†—The extraction of crude benzole (by washing the gas with heavy tar oil or petroleum "gas oil," afterwards steam distilling the benzolised oil to recover the crude benzole and prepare the oil for use again) was introduced into the gas industry during the war on a large scale. This additional source was the only means by which adequate supplies of benzene, toluene, etc., could be obtained for the manufacture of high explosives.

For some time after the war motor spirit was prepared from the crude benzole, but the market price obtained is now so low that benzole is worth more as an enricher in the gas, especially where continuous vertical carbonisation with steaming of the charge is practised. The benzole allows an increased amount of steaming, thereby producing more gas per ton of coal—the increase in volume of gas being obtained at a relatively low cost.

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*The cyanide recovered in the most profitable times, represented only about 5,000 tons of hydrocyanic acid, or approximately 20 per cent. of that possible if all gas had been treated.

†Owing to the high volatility of benzene, toluene, etc.—the chief constituents of crude benzol—the gas retains about 20 times more of these bodies than the quantity dissolved out by the tar.

TABLE II.—STATISTICS RELATING TO THE STATUTORY GAS UNDERTAKINGS. COAL, OIL AND THE BY-PRODUCTS COKE, TAR AND LIQUOR.

COAL GAS.

Year.	(1) A. No. of undertakings. Y.	B. Coal carbonised. Tons.	C. Coal gas made. 1,000 cu. ft.	D. Total coke and breeze made. Tons.	(2) E. Coke for heating retorts. Tons.	(3) F. Coke and breeze for sale. Tons.	(4) G. Coal tar. Galls.	(6) H. (Liquor) as sulphate of ammonia. Tons.
1922	796	15,907,095	201,963,546	10,475,155	2,070,000	7,347,246	162,860,531	113,373
1923	790	16,460,632	217,756,730	11,098,169	2,140,000	8,051,452	175,552,574	117,166
1924	784	17,329,180	231,886,036	11,657,465	2,250,000	8,431,099	188,327,278	124,737
1925	781	17,031,172	231,347,681	11,398,382	2,210,000	8,034,969	184,968,304	125,875

CARBURETTED WATER GAS.

Year.	J. Coke used. Tons.	K. Gas oil used. Galls.	L. Carburetted water gas. 1,000 cu. ft.	(5) M. Carburetted water-gas tar. Galls.
1922	1,057,909	46,145,160	43,946,129	6,910,000
1923	906,717	42,751,644	38,347,643	6,410,000
1924	976,366	45,460,609	39,268,220	6,820,000
1925	1,153,413	61,382,649	48,173,291	9,200,000

(1) Figs. in columns A. B. C. D. G. H. J. K. L. from Board of Trade Returns.
(2) Column E.=13 per cent. of coal, column F.
(3) Column F=Columns D—(E+J).
(4) Column G.=Board of Trade Returns for Tar corrected for Water-Gas Tar Column M.
(5) Column M.=15 per cent. of gas oil used in Column K.
(6) Sulphate equivalent of Ammoniacal Liquor.

Napthalene Removal.—Many works find it necessary to remove from the gas the small amount of naphthalene which has escaped solution in the tar. This is done as a precaution against naphthalene stoppages in domestic gas-pipes, etc. Where benzole recovery is practised the naphthalene passes into the crude benzole. When only naphthalene is to be removed it is done by scrubbing the gas with oil, but a very small quantity is used, and consequently the gas is not seriously denuded of crude benzole. The spent wash oil may be disposed of as a by-product, usually at a loss, or in the case of " spent gas oil " it may be used for

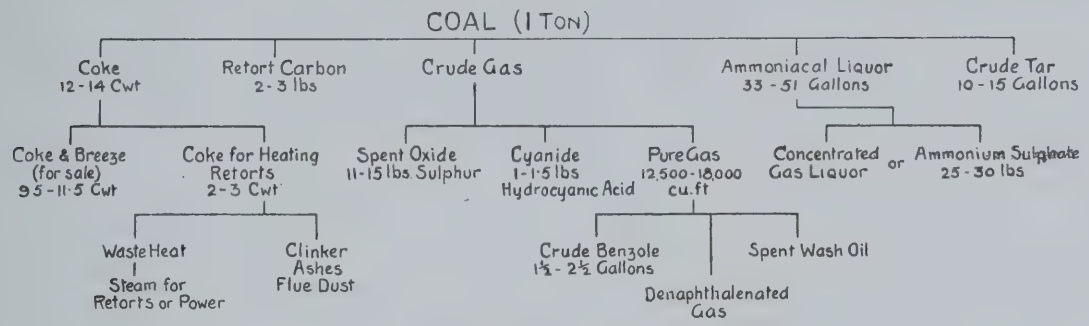

FIG. 1.—*Gasworks Products from Distillation of Coal.*

enrichment on the carburetted water-gas plants, although this latter method is open to criticism as being likely to overload the carburetted water gas with naphthalene.

Carburetted Water-gas Tar.—The manufacture of carburetted water gas results in the production of the by-product " carburetted water-gas tar."

The by-products of gas manufacture are shown in the chart, Fig. 1, and in Table I. below.

TABLE I.

	Yield.
Coke and breeze for sale	Approximately 9.5 to 11.5 cwt./ton.
Tar	10 to 15 galls./ton.
Ammoniacal liquor	Equivalent to 25 to 35 lbs. of ammonium sulphate,
Spent oxide	,, ,, 11 to 15 lbs. sulphur/ton.
Crude cyanide material	,, ,, 1 to 1½ lbs. hydrocyanic acid/ton
Spent wash oil	,, ,, 0.15 to 0.25 lbs. naphthalene/ton.
Crude benzole	1½ to 2½ gallons/ton.
Carburetted water-gas tar	Equivalent to 15 per cent. of oil used for enrichment.‡

Magnitude of industry.

The quantities of coal and oil used and the make of the chief by-products—coke, tar and liquor—are given in Table II. for the years 1922 to 1925 based on the Board of Trade returns for the statutory or Authorised Undertakings.

There are also about 800 non-statutory undertakings, but these are so small that so far as can be judged they only use in total about 500,000 tons of coal per annum. Their quota of residuals must be added to those in the table.

Since the bulk of liquor is used for making ammonium sulphate, it is usual to give its equivalent in terms of sulphate, as per column H.

‡Based on Seventh Report of the Institute of Gas Engineers' Research Committee.

Financial aspects.

The chief object of the gas industry is to make a combustible gas of suitable heating value and sell it as cheaply as possible. To this end, the net credits obtained from residuals or by-products are used for reducing the cost of gas manufacture. The " credit " by-products embrace coke, tar, liquor and occasionally " cyanide material " and " crude benzole." The by-products, " spent oxide " and " spent wash oil," scarcely realise enough money to cover the cost of their removal from the gas, and therefore are usually debits to the cost of gas manufacture. Oxide purification usually incurs a net cost of 3d. to 6d. per ton of coal, though on some works it is cheaper and on others dearer than this. Naphthalene washing costs anything up to 2d. or 3d. per ton of coal.

Since it is possible to make combustible gases from the most important by-products—coke and tar—the question arises as to which is the most profitable way of disposing of them.

The combustible gas from coke is made by the action of steam on incandescent coke forming blue water-gas. This gas has a relatively low heating value (approx. 300 B.Th.U.'s gross, per cu. ft.), and consequently only a limited quantity can be mixed with the richer coal gas, the amount depending upon the heating value required for the combined gas. Any additional quantity made must be carburetted, i.e., enriched with gas obtained from the " cracking "* of oil, and is then known as " carburetted water gas."

Since the monetary value of coke is a credit to the manufacture of coal gas, but a debit to water gas, a high value for coke reacts favourably on coal gas, but adversely on water gas. Owing to fluctuations in the market value of coke, cost of gas oil and labour, it pays at times to increase the amount of water gas at the expense of the coke, and at other times, to sell more coke.

It should be pointed out that carburetted water gas plants can be started up from cold very quickly as compared with coal gas retorts, and are used very extensively for meeting the sudden demands for gas occasioned by " cold snaps," etc. In these circumstances the necessity of maintaining an adequate supply of gas to the community outweighs the question of relative costs of water gas and coal gas.

Many attempts have been made from time to time to gasify coal tar by cracking, either in the vapour state (before deposition from the hot crude gas), or by injection of liquid tar into incandescent coke. Many practical difficulties are encountered, such as stopped pipes, etc., and the results have proved so poor that this method of disposing of tar cannot compete with its sale as a by-product. It should not be overlooked that coal tar itself is a product resulting from the partial " cracking " of the primary tars first evolved from the coal in the retort. The extent of this " cracking " depends upon the method of carbonisation and is undoubtedly an important factor not yet thoroughly explored in the economics of gas manufacture by different carbonising systems.†

The financial value of the chief by-products is illustrated in Table III. These figures are based on information from " Field's Analysis of Accounts of the Principal Gas Undertakings," for the years 1922 to 1925. The year 1926 is omitted owing to the disturbing effect of the coal mines dispute. The figures are the averages of about a dozen undertakings. The approximate cost of coal has been calculated from the " composite cost of coal," as given in the above analysis, by making appropriate allowances for the costs of gas oil and coke used on water-gas plants. The receipts, given as percentages on the cost of coal, show very clearly the relative importance of the by-products to the gas industry. Coke is by far the most valuable, then tar and finally liquor.

The very noticeable fluctuations in values owing to changing markets is a never-ending cause for anxiety to the managers of the gas industry. The steady decline in returns for liquor reflects the serious competition that gasworks' ammonium compounds (chiefly sulphate) are receiving from the synthetic ammonia industry. The comparative return in 1913 was 2/1.23 per ton of coal, which was about 15 per cent. of the cost of coal at that time.

It is now proposed to deal with the by-products, tar, liquor, and spent oxide, individually.

COAL TAR.

Coal tar, once an embarrassing waste product, has provided a very fruitful field for the chemist during the last few decades. As a result of research and commercial enterprise, a great variety of interlock-

*The production of permanent gas from tar or oil by heat is called " cracking."
†See Cantor Lectures by E. V. Evans. *Gas Journal*, 1924.

TABLE III.

QUANTITY AND COST OF COAL.

Year.	Coals Carbonised. Tons.	Approximate Cost of Coal per Ton. s. d.
1922	2,148,468	27/4.8
1923	2,359,862	25/3.5
1924	2,348,248	25/3.0
1925	2,332,364	24/1.4

RECEIPTS FOR BY-PRODUCTS.

Year.	Coke per ton. s. d.	Tar per gallon. d.	Liquor per gallon of 10-oz. d.
1922	21/3.88	4.73	0.643
1923	23/6.39	5.60	0.544
1924	24/6.38	3.45	0.371
1925	18/10.91	3.31	0.338

RECEIPTS FOR BY-PRODUCTS PER TON OF COAL.

Year.	Coke and Breeze. s. d.	Tar. s. d.	Liquor. s. d.	Total. s. d.
1922	10/11.62	4/8.94	1/7.95	17/4.51
1923	11/11.55	5/8.22	1/4.65	19/0.42
1924	12/4.68	3/6.53	1/0.01	16/11.22
1925	9/5.88	3/5.30	10.92	13/10.10

RECEIPTS FOR BY-PRODUCTS AS PERCENTAGE ON COST OF TON OF COAL.

Year.	Coke and Breeze. %	Tar. %	Liquor. %	Total. %
1922	40.0	17.3	6.1	63.4
1923	47.3	22.4	5.5	75.2
1924	49.1	14.0	4.0	67.1
1925	39.3	14.3	3.8	57.4

ing chemical industries have been built up, dependent upon tar and its products for their most important raw materials. These industries fall into two main classes, (1) those which make synthetic and refined products using as a starting point a relatively small number of pure substances (equal in bulk to about 10 per cent. of the whole of the tar) such as benzene, toluene, naphthalene, phenol, anthracene, and (2) those which use much less refined materials, usually referred to as the " coal-tar crudes," such as benzoles, naphthas, carbolic oils, creosote oils, pitch, etc., totalling about 90 per cent. of the bulk of the tar.

The preparation of the various tar products for these industries is carried out by the distillation and subsequent treatment of crude tar in the tar distilleries. In this connection it is necessary to take into account the coal tar made during the manufacture of metallurgical coke by the by-product coking industry. This tar, together with that from the gas industry, accounts for 98 per cent. of the total coal tar made in Great Britain. The annual production of coal tar based on the Alkali Inspector's returns for 1923, 1924 and 1925, averages 323,000,000 gallons. According to the Board of Trade Returns for 1923, 1924 and 1925, the statutory gas undertakings contribute on the average 190,500,000, to which should be added about 5,000,000 gallons for the non-statutory companies, giving a total of 195,500,000 gallons.

The tar from the gas industry includes about 7,500,000 gallons of carburetted water-gas tar—calculated on a 15 per cent. yield from the gas oil used (see Seventh Report of the Gas Investigation Committee, Institute of Gas Engineers). This leaves coal tar, 188,000,000 gallons, which as far as can be ascertained is composed of equal quantities of horizontal retort tar and vertical retort tar. Most by-product coke-oven works completely distil their own tar, but only a few of the larger gas undertakings follow this course, though because of their size they account for quite a large proportion of gasworks' tar, viz., 60,000,000 to 70,000,000 gallons per annum, or approximately 31 per cent. Most of the undertakings sell their tar to outside distilleries. Those undertakings who make road tar by simply distilling off the water and a small portion of oil retain sufficient tar for this purpose. During recent years a number of co-operative schemes have been entered into between the gas undertakings and tar distillers in certain large areas. The distiller undertakes to keep the gasworks free from embarrassing accumulations of tar, pays an agreed minimum price for tar of suitable water content, and shares any additional profit on an agreed schedule. The co-operative schemes already in existence deal with about 60,000,000 to 70,000,000 gallons per annum.

It is hoped that this co-operative dealing with tar will help to stabilise a very fluctuating market, eliminate wasteful competition, and thus prove beneficial to all parties.

Constitution of tars.

It is well known that coal tars are mixtures of a few hundred organic compounds, some present in appreciable quantities, others as mere traces. Many of these compounds are common to most tars but vary in quantity from one tar to another. Not only do the tars from different coals vary in composition, other things being equal, but the method and temperature of carbonisation have a profound effect on composition. This accounts for the difference observable in tars made by carbonisation in horizontal retorts and that from continuous vertical retorts, the two important carbonising systems of the gas industry. The tars from coke ovens more closely approach in composition tar from horizontal retorts. When coal is heated to a dull red heat it gives off primary "low-temperature tars," which are characterised by the presence of paraffinic and naphthenic hydrocarbons, and in addition to other substances contain complex oxygenated bodies soluble in aqueous solutions of alkalies and known as "tar acids." When these primary tars come into contact with highly-heated coke and retort walls, as they do when coal is carbonised in horizontal retorts and coke ovens, they are decomposed or "cracked" into gases, solids, and a reduced quantity of "high-temperature tar." This tar is characterised by the presence of organic bodies possessing the benzenoid structure. The tar acids are altered in composition and reduced in quantity. In continuous vertical retorts, however, the coal is gradually heated up as it descends the retort and since the crude gas is taken off at the top much of the primary tar does not come into contact with highly-heated surfaces, and therefore escapes decomposition. Tar produced in the carbonising zones further down the retort coming into contact with hot surfaces in its ascent undergoes a corresponding degree of cracking.

It follows, therefore, that vertical tar consists of a mixture of tars produced from coal at different temperatures ranging from "low-temperature tar" to "high-temperature tar." Vertical tar has lower specific gravity and viscosity than horizontal tar, and a higher yield per ton is obtained.

Horizontal retort tar contains more solid and semi-solid decomposition products, which prove insoluble in benzene than is the case with vertical retort tars. This insoluble material produced from the cracking of primary tar is conventionally, but very mistakenly, called "free carbon."

The quantity of vertical retort tar made has rapidly increased of late years. When it is remembered that the tar industry and its many dependent industries have been developed on tar from coke ovens and horizontal retorts, it is not surprising to find that vertical retort tar, owing to the above difference in composition, causes a degree of embarrassment in certain of these industries. However, it is already being appreciated that vertical tars contain compounds which will doubtless find special uses and open up still more avenues for the use of tar products.

PREPARATION OF TAR AND ITS PRODUCTS FOR THE MARKET.

Road tar.—The greatest single purpose to which suitably prepared tar is put is that of road spraying. This industry has made rapid strides the last few years, and is mainly responsible for our excellent roads.

According to the recently formed British Road Tar Association approximately 97,500,000 gallons or 500,000 tons of prepared tar are used per annum, *i.e.*, about 30 per cent. of all the tar in the country. Crude tar itself is not satisfactory, but by distilling off the liquor and some of the light oils a highly suitable product remains. The quantity of distillate depends on the nature of the tar. From experience gained in the use of tar for roads, a specification has been drawn up by the Ministry of Transport to which road tars should conform, and with some tars a certain amount of blending with other tar fractions improves the product still further. Prepared road tar makes first-class, non-skid, durable roads, and moreover its use for this purpose provides a valuable outlet for a British product, thereby improving British trade.

It has been found that road tar made from vertical retort tar by simple dehydration differs in certain characteristics from that similarly prepared from horizontal retort and coke-oven tars. This matter, along with many others is receiving attention by the British Road Tar Association, and the evidence shows that equally useful and highly satisfactory road tars can be prepared from either source.

Complete Distillation of Tar.—Apart from the preparation of road tar the distillation of the remaining 60 to 70 per cent. of the annual production is carried much further, and the distillates collected or "cut" into various successive fractions. The "cut points" are usually controlled by making use of the increasing gravity of the distillate and the distillation is finally stopped at such point as will leave the desired quality

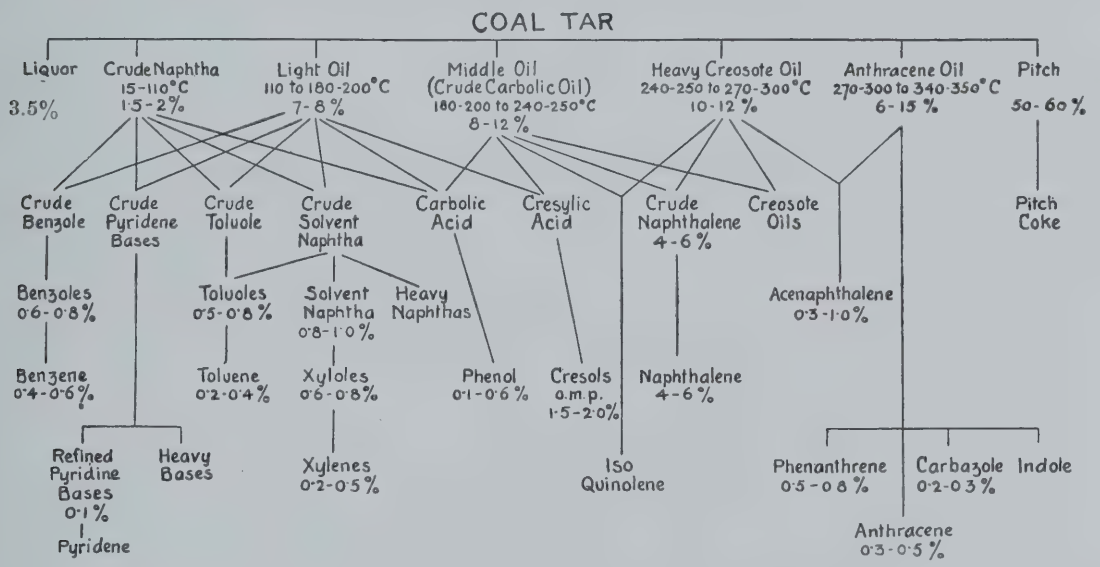

FIG. 2.—*Products from Distillation of Coal Tar. Yields are only approximate; they vary considerably between different tars.* (*Compiled by Bunbury and Davidson.*)

of pitch, usually that styled as "medium soft pitch." The number of fractions collected and the "cut points" are varied according to the nature of the tar and the market demands which the distiller wishes to meet.

A fairly full range of fractions is indicated in Fig. 2, and serves to illustrate the preliminary distillation and the nature of the subsequent tar products frequently made for the market.

It is not suggested that any one works will conform to the whole of this programme, or that the yields cover all tars met with in practice. The tars from heavily-steamed vertical retorts will be notable exceptions—with, among other items, their low carbolic-acid and high creosote yields.

It should be mentioned here that some tar distillers, including a few large gas undertakings, go a stage further than the preparation of pure products, such as benzene, by preparing the compounds which constitute the next step in the production of dyes, etc., *i.e.*, the "Intermediates."

USES OF COAL-TAR PRODUCTS (other than for road purposes).

The Fuel Industry.—It will be seen that by far the largest single crude fraction in tar distillation is pitch, constituting 50 to 60 per cent. of the original tar. Until the demand for road tar

arose this was the most important fraction financially. Pitch is used chiefly as a binder in the briquetting of coal slacks (8 to 10 per cent. binder being added), and this industry is feeling the severe effect of the demand for road tar. This is reflected in the returns for pitch as given by the Alkali Inspector's Reports, which show a steady decline in pitch made.

TABLE IV.

Date.	Total Tar Distilled.	Total Pitch Made.	Percentage Pitch/Ton of Tar.
1920	1,592,081	739,556	46.4
*1921	1,129,425	425,360	37.6
1922	1,314,995	490,573	37.3
1923	1,586,243	624,641	39.4
1924	1,730,350	580,591	33.5
1925	1,648,454	499,582	30.0
*1926	1,296,822	300,778	23.2

*Abnormal, due to Coal Disputes.

About 40 per cent. of the pitch made is used for briquetting in South Wales, and the manufactured briquettes are then exported. The other 60 per cent. of pitch is exported chiefly to the Continent. The relative merits of pitches from vertical retort tar and horizontal retort tar as briquetting binders are receiving considerable attention in the briquette and tar industries. It is not surprising to find that there are some differences in properties.

Pitch Coke.—If pitch is distilled to a red heat a very dense form of carbon ("pitch coke") is produced, equal to about half the pitch, and is used as a special fuel and for electrode manufacture.

Benzole.—The important use of benzole for motor fuel requires no further comment. This material is now produced chiefly from tar and by gas washing at the by-product coke-oven works.

Creosote and other Heavy Oils.—These prove valuable fuel oils in times of emergency and were extensively used during the war.

Crude Naphthalene finds an extensive use in fire-lighters.

Burning Naphthas are used in lamps to a very small extent.

Solvents.—Crude tar fractions, such as benzoles, toluoles, solvent naphthas and pyridines find a very wide field for use as solvents in a multitude of industries, such as rubber, paint, varnish, dry cleaning, and in the manufacture of organic chemicals, etc. The pure tar products are also used as solvents. Anthracene oil is often used when gas is "stripped" for benzole by oil washing.

Timber preservatives.—Creosote oils, containing specified percentages of "tar acids" find an enormous outlet, particularly in America, for creosoting rail-road cross-ties, telegraph poles, etc. In 1925 we exported approximately 38,000,000 gallons of creosote and tar oils, chiefly to America, which used during that year the huge quantity of 167,000,000 gallons.

Disinfectants, Insecticides, etc.—Are prepared in large quantities from tar fractions containing specified percentages of the tar acids such as carbolic, cresylic, etc.

Synthetic and fine chemical industry.

Of the tar products which find the widest use in the synthetic and fine chemical industry may be mentioned the pure substances—benzene, toluene, phenol, naphthalene and anthracene. Then come the xylenes, cresols, phenathene, acenaphthalene, carbozole, pyridine, etc. One or other of these materials forms the starting point for a vast number of organic compounds, including coal tar dyestuffs, explosives, drugs, antiseptics, photographic chemicals, rubber accelerators, perfumes, synthetic resins, tannins and solvents.

AMMONIACAL LIQUOR.

Of the 1 to 1½ per cent. of nitrogen present in gas coals about 15 to 20 per cent. appears as ammonia in the crude gas, and with proper cooling and scrubbing this finds its way into the ammoniacal liquor. Ammonia being a powerful base combines with the acidic impurities hydrochloric acid, sulphuretted hydrogen, carbon dioxide, hydrocyanic acid, etc., and takes them into solution in the liquor, thereby effecting a partial purification of the gas. The composition of the liquor is further complicated by chemical interaction and oxidation of these compounds. When ammoniacal liquor is boiled many of these compounds dissociate and the liquor evolves steam and a mixture of gases consisting chiefly of ammonia, sulphuretted hydrogen, carbon dioxide and a little hydrocyanic acid. The evolved ammonia is said to be " free " in contrast to the " fixed " ammonia which remains behind as chloride, etc. If an alkali such as lime be added to these fixed salts, they too are decomposed and the ammonia given off. According to Alwyne Meade, ammonia liquor may contain:—

Ammonium Carbonate.	" Free " ammonia 75-80% of total ammonia.	Ammonium Chloride.	" Fixed " ammonia 20-25% of total ammonia.
,, Bicarbonate.		,, Sulphocyanide.	
,, Carbamate.		,, Sulphite.	
,, Sulphide.		,, Thiosulphate.	
,, Hydrosulphide.		,, Sulphate.	
,, Cyanide.		,, Ferrocyanide.	
,, Polysulphide.		,, Acetate.	

Also phenols, amines and other nitrogenous bodies.

The strength of liquor is gauged by the number of ounces of pure H_2SO_4 which could be neutralised by the whole of the NH_3 in one gallon of liquor, *e.g.*, 1 gallon of 10-oz. liquor contains sufficient ammonia to neutralise 10 ozs. of pure H_2SO_4, ; it contains 2.115 per cent. of ammonia, equivalent to 4.85 cu. ft. of ammonia gas at 60° F. and 30″ Hg. Approximately 2,660 galls. of 10-oz. liquor are used per ton of sulphate.

The quantity of ammonia and strength of liquor made per ton of coal carbonised depends upon (1) moisture content and composition of coal; (2) system and temperature of carbonisation; (3) degree of steaming and amount of scrubbing water. As a very rough approximation, the Effluents Committee of the Institution of Gas Engineeers have adopted as a basis the average figures of 33 gallons of 9-oz. liquor from horizontals and 51 gallons of 7-oz. liquor from continuous verticals.

The bulk of ammoniacal liquor is worked up as sulphate of ammonia, being first of all subjected to distillation in suitable stills of the continuous type, which usually embody a section for the introduction of lime for releasing the " fixed " ammonia.

The steam and gaseous products containing ammonia, carbon dioxide, sulphuretted hydrogen and hydrocyanic acid are passed into a saturator containing sulphuric acid and the ammonium sulphate formed crystallises out and by further treatment such as " whizzing," neutralising and drying, is made ready for the market.

The steam and gases pass through the saturator and are cooled, giving an evil-smelling condensate termed " devil liquor " containing sulphides, cyanides, etc. The sulphuretted hydrogen is absorbed by passing through oxide of iron and the carbon dioxide escapes into the atmosphere. The effluent liquor consisting of condensed steam, spent liquor and lime passes away from the bottom of the still to settling tanks. This effluent owing to its deleterious effect must be excluded from waterways.

The best method of dealing with it has formed the subject of research of the Chief Alkali Inspector for some considerable time, and a special Liquor Effluents Committee† of the Institution of Gas Engineers is investigating the problem on the following lines:—(a) Modification of usual practice with a view to decreasing the amount of spent gas liquor; (b) modifications of usual practice with a view to improving the composition of spent gas liquors; (c) methods proposed for the purification or disposal of spent gas liquor.

Apart from sulphate manufacture a certain amount of ammoniacal liquor is distilled and the ammonia gas collected in water, giving solutions of desired concentrations and degrees of purity—the latter depending

†First Report of Liquor Effluents Committee. *Gas Journal*, July, 1927.

upon the extent to which the impurities, sulphuretted hydrogen, carbon dioxide, etc., are eliminated. These solutions comprise:—

Concentrated Gas Liquor.—Made in considerable quantity and containing 16 to 18 per cent. of ammonia in association with sulphuretted hydrogen and carbon dioxide. Made by several gasworks, and used extensively in the manufacture of soda by the ammonia-soda process.

Concentrated Ammonia Liquor.—Made in considerable quantity containing 22 to 26 per cent. ammonia containing little sulphuretted hydrogen or carbon dioxide. Used in the cyanide industry and for the preparation of other ammonium salts.

Pure Caustic Ammonia.—An aqueous solution of any desired strength up to 36 per cent. (.880 ammonia) of purified ammonia gas. Used for dyeing, bleaching, scouring of wool, and the preparation of pharmaceutical products, etc. Weak solutions up to 12 per cent. ammonia are used for household cleansing purposes.

Liquefied Ammonia—Made by drying the pure ammonia gas and compressing into steel cylinders. Used in the refrigerating industry, and as a solvent for chemical purposes.

Ammonium Nitrate.—Among other ways made by neutralising nitric acid with gaseous ammonia, or concentrated ammoniacal liquor. Used for explosives, and was made on a large scale during the war. The difficulty of using it as a fertiliser is its great propensity for caking. It is also used in freezing mixtures.

Ammonium Chloride.—Made among other ways by neutralising hydrochloric acid with gaseous ammonia or concentrated gas liquor. Used for soldering and galvanizing work, also calico printing.

Ammonium Carbonate.—Made by the reaction in suitable chambers of gaseous ammonia, carbon dioxide and water. Used for wool washing and as an ingredient of baking powder.

Ammonium Phosphate.—Used in sugar refining.

Ammonium Thiocyanate.—Used in photography.

FUTURE OF GASWORK'S BY-PRODUCT AMMONIA.

Until recent years the main sources of nitrogenous fertilisers were by-product ammonia and Chilean nitrate of soda. During and since the war, however, the fixation of atmospheric nitrogen and the production of synthetic sulphate in a very pure form have developed at a rapid rate. This competition in the world markets has already seriously reduced the profits on by-product sulphate. The world's production of sulphate of ammonia according to the Sulphate of Ammonia Federation was 2,973,700 tons for year ended May, 1926, consisting of approximately equal quantities of by-product and synthetic. British gasworks contributed 171,000 tons; by-product coke-oven and other works contributed 258,500 tons ; and synthetic works approximately 100,000 tons.* This latter figure is rapidly increasing.

About 40 per cent. of the present cost of making by-product sulphate of ammonia is due to sulphuric acid, of which 18.5 cwt. of 144° Tw., equal to 15 cwts. 100 per cent. acid, are required per ton of sulphate.

Some large works reduce their cost for acid by making it from their own spent oxide, thereby cutting out cost of carriage to and from an outside works. The sulphur from purification is more than sufficient for producing the acid required. This only pays on large works which have the necessary organisation and capital to take their place in the heavy chemical industry, and consequently most works buy their acid from outside, or sell their liquor to an outside chemical works. The relatively high price of sulphuric acid is said to be due to high overhead charges on plant which is idle owing to poor demand. It should be borne in mind that although a low price for acid helps to reduce sulphate costs, it reacts unfavourably on spent oxide returns. A recent advance in sulphate of ammonia manufacture is the use of anhydrite (calcium sulphate) by the synthetic ammonia industry to supply the sulphate " radical " to ammonia instead of using manufactured sulphuric acid. This is said to be more economical. Rigid economies effected at various points in its manufacture make by-product sulphate of ammonia profitable for some time to come. In any case the gas industry will have to continue converting its ammonia into saleable products in order to dispose of it. Ammoniacal liquor presumably would be harder to dispose of as such than the effluent from its distillation.

*Based on data given by Col. Pollit at Edinburgh Conference, July, 1927. Soc. Chem. Ind.

The fall in the value of ammonia should give an impetus to investigation into alternative purification processes, especially that of the liquid purification of coal gas by means of ammonia, which proved too costly just before the war, due to the ammonia losses attendant on the process.

These losses would not have the same importance now. The cost of this process after getting as good a price for the ammonia and sulphur as possible, might prove less than the loss on oxide purification plus the possible loss on liquor.

SPENT OXIDE.

Crude gas contains 1 to 2.0 per cent. by volume of sulphuretted hydrogen, which must be removed until the gas does not stain a lead acetate paper as used in the test prescribed by the Gas Examiners. A proportion of this is removed in the ammoniacal liquor but the bulk is removed by oxide of iron.

Spent oxide is used as a substitute for pyrites and native sulphur in sulphuric acid manufacture, and during the last few years has become increasingly popular as will be seen from the figures in Table IV. relating to sulphuric acid manufactured in Great Britain. About 13.7 cwt. of oxide containing 50 per cent. sulphur are required per ton of acid.

It is sold on its sulphur content, prices being based on a sliding scale according to the " units " of sulphur per ton, each " unit " being 1 per cent. of sulphur per ton. The oxide after " burning " can be prepared again for use in the purifiers.

Spent oxide is the only home source of sulphur for sulphuric acid and the tendency will be to use the whole of the available supply in preference to the imported materials. Incidentally, spent oxide is said to be much easier to handle and gives an acid relatively arsenic-free, speaking commercially, a distinct point in its favour.

TABLE IV.

Year.	Output of 100% acid. Tons.	Percentage made from Pyrites.		Percentage made from		Percentage made from Zinc and Copper bases. %
		Imported. %	Domestic. %	Spent oxide. %	Sulphur. %	
1914	1,082,000	88.5	0.45	10.6	0.3	0.15
1917	1,382,000	79.9	0.7	11.0	8.1	0.30
1918	1,380,000	79.4	1.6	11.2	7.4	0.40
1919	883,000	80.3	0.8	15.9	1.8	1.20
1920	1,053,000	80.4	0.9	16.7	1.2	0.8
1921	560,000	71.0	1.0	24.0	3.6	0.4
1922	817,000	61.8	1.1	25.5	9.6	2.0
1923	873,000	51.1	1.1	23.2	21.5	3.5
1924	918,000	48.5	1.0	22.8	23.6	4.1
1925	848,000	45.9	1.0	23.8	23.7	5.6

Chapter 3.

BLUE AND CARBURETTED WATER GAS, COMPLETE GASIFICATION, Etc.

By A. Parker, D.Sc., F.I.C., M.I.Chem.E.

The object of this chapter is to review the methods of manufacture of water gas and other supplementary gas-making processes adopted in the production of gas for town supply. The subject is considered with a view to directing attention to the heat losses which occur and the possibilities of improvements towards the more efficient utilisation of the fuel employed. The various modifications of the different processes cannot be considered in detail in the space available, but descriptions of some typical examples are given in illustration of main principles.

The gas supplied by most of the smaller undertakings, with an output of less than 250 million cubic feet per annum, consists entirely of coal gas made in continuous vertical retort systems or in horizontal retorts; but these undertakings produce only about 12 per cent. of the total volume of gas distributed in Great Britain. The larger undertakings in most instances distribute a mixture of coal gas and water gas, the latter generally being raised to the desired quality by means of enriching oil. The importance of water gas in the gas industry is illustrated by the fact that during 1925 approximately 17 per cent. of the total gas supplied consisted of carburetted water gas.

As an adjunct to the usual retort systems, water gas generators possess the distinct advantage that they can be put in operation in a few hours in case of breakdown of other plant, and that sudden demands for gas can rapidly be met. Water gas plants are extremely valuable in providing a means whereby gas undertakings can, in some measure, regulate the output of coke according to the needs of the particular locality. They also provide a useful alternative method for the production of gas with the maximum conservation of coal during periods of coal shortage. This advantage was well illustrated during the latter half of 1926, the period of industrial difficulty in the coal mining industry, when more than 40 per cent. of the gas manufactured by several large undertakings in this country consisted of carburetted water gas. The calorific value of blue water gas is approximately 300 B.Th.U. (gross) per cubic foot, but by enrichment with oil the calorific value can be readily increased to any required amount between 300 B.Th.U. and 600 B.Th.U. per cubic foot, according to the quantity of oil employed. This ease of control of the quality of the gas made is useful in those instances where coal gas and water gas are admixed in ensuring the distribution of a mixed gas of uniform calorific value.

Water gas plants are erected with a smaller capital expenditure than coal carbonisation installations of equivalent capacity, and they are operated with lower labour charges. The overall cost of production of blue water gas is largely dependent on the market value of coke, and with carburetted gas the cost is also influenced by the price of oil. High values for coke and oil result in the costs of production of both varieties of water gas being greater per therm than coal gas, but in considering costs it must be remembered that the utilisation of coke in the manufacture of water gas may influence the market value of coke for other purposes.

A large number of systems have also been designed, and some have been operated on a commercial scale, in which the manufacture of water gas and the carbonisation of coal are carried out in one installation in such manner that the whole, or a large proportion of the coal employed is gasified.

BLUE WATER GAS.

The blue water gas process, according to general British practice, may conveniently be divided into two distinct operations. The hot fuel, coke, is first raised to a high temperature by the admission of air. This operation known as the "blow" occupies from one to three minutes. The gases produced are blown away to the atmosphere through the stack, either direct or after combination with air and passage through a waste-heat boiler. When the temperature of the coke has been raised to the required degree the air supply is closed, and the bed of fuel is submitted to the action of steam supplied at a measured rate. The steaming operation known as the "run," occupies from four to ten minutes, according to the cycle of operations adopted. The blow and run operations are carried out alternately during a period

of several hours, at the end of which the operations are suspended for the removal of ashes and clinker, unless mechanical grates are provided.

The addition of heat to the bed of fuel during the blow periods results mainly from that developed by the oxidation of carbon to carbon monoxide and carbon dioxide, and provided other conditions remain unchanged, the degree of heat addition is dependent on the proportion in which these two gases are produced. More than three times as much heat is liberated when the product is wholly carbon dioxide as when only carbon monoxide is obtained. The aim during the air-blow should therefore be to obtain the maximum amount of carbon dioxide. The oxidation to carbon dioxide predominates at lower temperatures, and the proportion of carbon monoxide produced increases as the temperature is raised. The efficiency of heat generation, therefore, decreases with rise of temperature.

During the run periods, when steam is passed through the bed of fuel, hydrogen, carbon monoxide and carbon dioxide are produced according to the following equations :—

1. $C + H_2O = CO + H_2$ *minus* 29 kg. cal.
2. $C + 2H_2O = CO_2 + 2H_2$ *minus* 19 kg. cal.

At temperatures above 1,000° C. the products of interaction of steam and coke are almost entirely carbon monoxide and hydrogen, and the rate of reaction is high if the temperature be maintained. At lower temperatures the importance of the second reaction increases, and the proportion of steam decomposed decreases.

In addition to the influence of temperature and time of contact on the proportion of steam decomposed, and on the extent to which the different reactions occur during the blow and run periods, certain ash constituents[1] of coke act catalytically in increasing the velocities of the reactions.

A consideration of the intermittent process of production of water gas shows that in order to obtain high efficiency of heat addition during the air-blow, the fuel should be kept at a comparatively low temperature, and the time of contact of the gases with the hot fuel should be as small as possible. On the other hand, to obtain a high efficiency during the steaming operation, the fuel must be maintained at a high temperature and sufficient time of contact must be allowed. These opposing factors must be taken into account in determining the conditions of best efficiency for the whole process.

Description of plant.

A typical general arrangement of a blue water gas plant is shown in Fig. 1, which represents the Humphreys and Glasgow plant employed in a series of investigations at Birmingham by the Joint Committee of the University of Leeds and the Institution of Gas Engineers.

The generator consists of a cylindrical steel shell lined with firebrick blocks. The bed of fuel, usually between six and seven feet in depth, rests on a flat bar grate, on a level with which are clinkering doors, and below which is a door for removing the ashes into a pit immediately beneath. The generator is connected by pipes both above and below the fuel bed with the bottom of the scrubber. During the blow periods the air enters at the bottom of the generator and the blast products travel through the outlet pipe at the top into the stack. During the run periods, when the stack and blast valves are closed, the steam enters either below or above the fuel bed and the resultant water gas is carried away to the scrubber by the outlet pipe at the top or bottom according to whether the steaming is being operated in an upward or downward direction. In this particular installation a catch pocket is so placed on the top outlet pipe, that it collects the heavier particles of coke carried forward during the blow period. The generator is charged with coke through the door at the top. The air for this installation is supplied by a Sturtevant blower driven by a steam turbine of the non-condensing type. In many installations the blower is electrically driven and various types of blower are in use.

From the generator the water gas made passes upwards through a scrubber in which it meets a rapid stream of cold water. The purpose of the scrubber is to remove tar and solid matter from the gas, to condense undecomposed steam and to cool the water gas. After leaving the scrubber the water gas passes to a relief holder, which serves to store the gas between the blow periods and to control the admixture of the water gas with coal gas.

[1]Marson and Cobb, Gas J., 1926, 175, 882.

Most of the water gas plants erected in gas works in this country are designed on the same principles as the plant already described. Of other types of blue gas systems, the Dellwik-Fleischer and the Kramer and Aarts plants have been employed extensively on the Continent, but have not been adopted to the same extent in Great Britain.

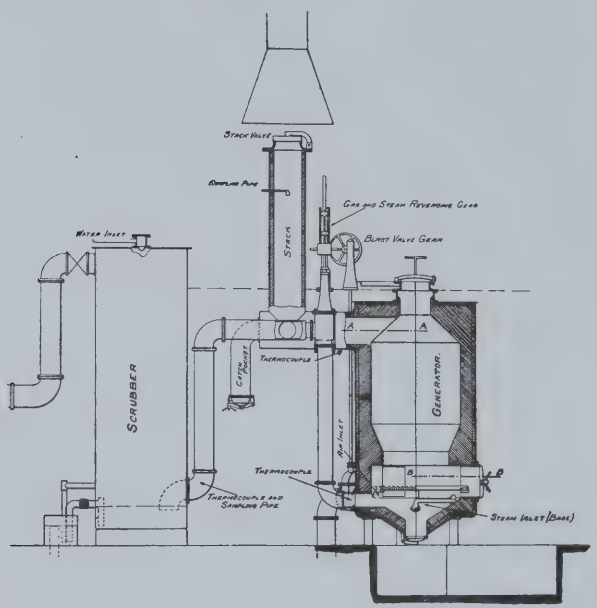

FIG. 1.—*Typical arrangement of a Blue Water Gas Plant.*

The Dellwik-Fleischer plant consists of a single generator supplemented by a steam superheater and a condenser and scrubber. The generator is shorter than that of the Humphreys and Glasgow system but much greater in diameter. There is thus obtained a broad shallow bed of fuel, from three to four feet in depth, which with a powerful air blast is designed to promote the maximum formation of carbon dioxide during the blow periods. Experiments conducted with carefully controlled shallow beds of fuel and high rates of air supply,[2] however, have produced blow gases containing large quantities of carbon monoxide, owing to the high velocities of the air-carbon reactions at the temperatures required in the manufacture of water gas. Amounts of carbon dioxide in the blow gas showing almost complete oxidation of carbon have been obtained, but under conditions which allowed the passage of unchanged oxygen through channels in the fuel, and the subsequent combination of this oxygen with carbon monoxide above the bed of fuel. The water gas made during the run periods, according to the Dellwik system, travels through an annular superheater in which a heat exchange is effected between the hot water gas and the steam supplied to the generator.

The Kramer and Aarts process (Fig. 2) employs two generators with superimposed regenerators filled with firebrick chequer work. The fuel beds are air-blown in parallel and the resultant gases pass through the regenerators to a stack at the top. The chequer work is heated up by the combustion of the blow gas by the admission of secondary air. During the run periods steam, superheated as in the Dellwik system, is admitted at the base of one generator and the product gases pass up through one regenerator and down through the second regenerator and bed of fuel. The Kramer and Aarts system, therefore, combines a comparatively shallow bed of fuel for the blow periods with a deep bed during the steaming operations. It is claimed that the percentage of steam decomposed is high and the water gas contains a relatively small quantity of carbon dioxide.

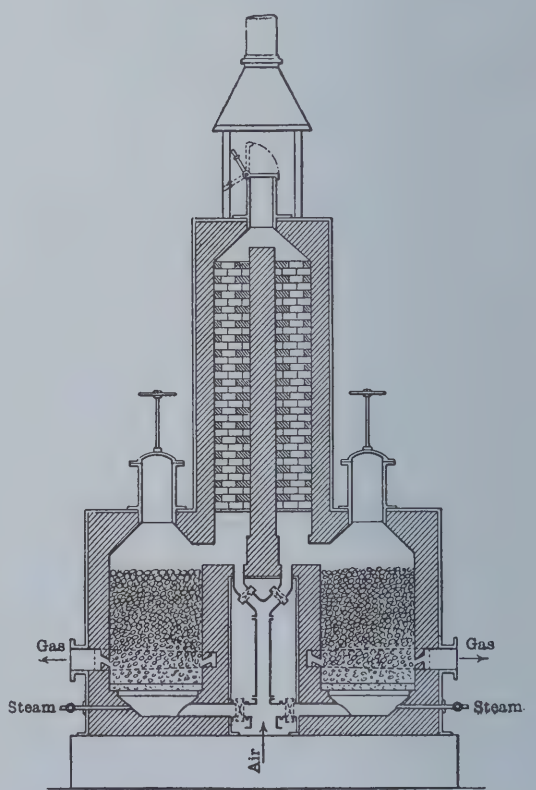

FIG. 2.—*Kramer and Aarts Blue Water Gas Plant.*

[2] Joint Research Committee, Tenth Report, 1923.

Results of operation.

The conditions of operation of blue water gas plants differ in detail according to the type and size of installation and the character of the coke available. The conditions productive of the best results in a particular plant and with a given coke can only be found by actual trials in which full data are obtained under scientific supervision. The coke supplied to the generator should be maintained as far as possible of the same quality and size grading, and the rates of supply of air and steam should be accurately controlled by means of reliable meters.

The results obtained during Test D of the Tenth Report of the Joint Gas Research Committee are typical of average commercial practice in the manufacture of blue water gas. The principal figures for this test, therefore, are given in Table I. The coke as charged into the generator contained 10.8 per cent. of moisture. The dried coke had a gross calorific value of 12,620 B.Th.U. per lb. and contained 12.3 per cent. of ash. The quantities of steam supplied to the generator and consumed by the turbine used to drive the blower are given in Table I. in tons per ton of dry coke employed in the generator. The proportion of steam decomposed in the generator was approximately 70 per cent., the remainder being carried forward with the water gas.

TABLE I.—MANUFACTURE OF BLUE WATER GAS.

Purified water gas made per ton of coke (dry basis), cubic feet		57,690	
Composition of water gas—volume per cent. :—		Composition of blow gas—volume per cent. :—	
CO_2	4.5	CO_2	12.1
O_2	0.1	O_2	0.1
CO	40.7	CO	13.8
H_2	49.2	H_2	2.4
CH_4	0.6	CH_4	0.3
N_2	4.9	N_2	71.3
	100.0		100.0
Specific gravity of gas (air=1)	0.55	Calorific value of blow gas, B.Th.U. gross per cubic foot	54.5
Calorific value of gas, B.Th.U. gross per cubic foot	296	Dry ashes withdrawn, tons per ton of dry coke	0.122
Thermal value of gas in therms gross per ton of dry coke	170.8	Dry clinker withdrawn, tons per ton of dry coke	0.035
Steam supplied to generator, tons per ton of dry coke	0.89	Coke dust from pocket, tons per ton of dry coke	0.015
Steam employed to drive blower, tons per ton of dry coke	1.04		

Carbon balances constructed to show the amounts of this element in the coke supplied to the generator, the water gas made, the blow gas produced, and in the ashes, clinker and coke dust withdrawn are given in Table II., in the first column of which the figures represent the weights of this element in lbs. per 1,000 cubic feet of water gas made. In the second column the amounts are expressed in percentages of the carbon in the coke supplied. The most important point brought out by this balance is that only 45 per cent. of the carbon consumed was converted into water gas; the blow gas together with small losses not separately determined accounted for 49 per cent. and 6 per cent. was removed with the ashes, clinker and coke dust.

TABLE II.—CARBON BALANCE.

	Lbs. per 1,000 c. ft. Blue water gas.	Per cent.
Coke to generator	31.87	100.0
Water gas	14.29	44.9
Ashes	1.38	4.3
Clinker	0.10	0.3
Dust	0.47	1.5
Blow gas, etc. (difference)	15.63	49.0
	31.87	100.0

For convenience in reference, a number of the results per 1,000 cubic feet of water gas made are given in Table III. The volume of air supplied was approximately 1,700 cubic feet, which produced 1,900 cubic feet of blow gas, or nearly twice the volume of water gas made.

TABLE III.—RESULTS PER 1,000 C. FEET. BLUE WATER GAS.

Coke (dry) in lbs. to generator	38.83	Blow gas produced, c. ft., at 60° Fahr. and 30 ins.	1,913
Carbon, in lbs., in coke to generator ...	31.87	Thermal value of water gas, therms gross...	2.96
Steam in lbs. to generator	34.6	Thermal value of coke to generator, therms gross	4.90
Steam in lbs. to blower turbine	40.4	Efficiency of gas production, per cent.—fuel for steam *not* taken into account ...	60.4
Total steam in lbs. to generator and turbine	75.0		
Air supplied, c. ft. at 60° Fahr. and 30 ins....	1,722		

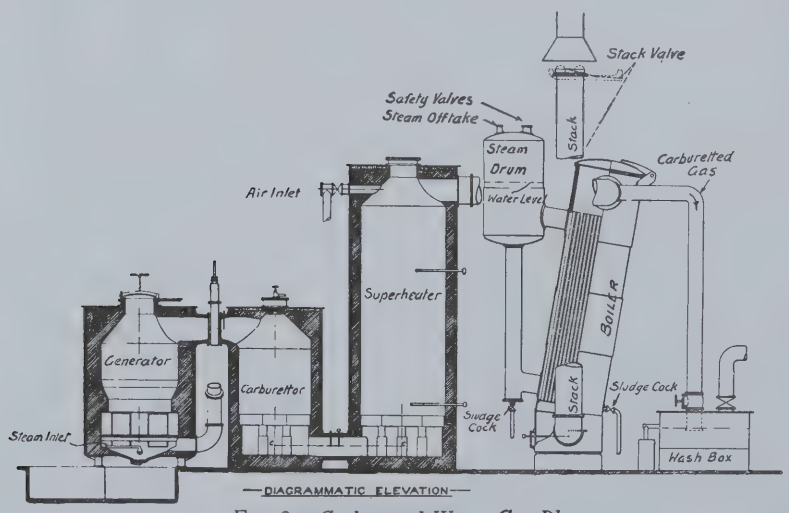

FIG. 3.—*Carburetted Water Gas Plant.*

Thermal efficiency of blue water gas process.

As an example of a thermal balance under conditions typical of British practice, Table IV. is given for Test D of the Tenth Report of the Joint Research Committee. Two sets of figures are shown in this table, the first in therms per 1,000 cubic feet of water gas made, and the second as percentages of the total heat supplied to the generator. In this thermal balance the heat supplied to the generator is represented by three items, coke, steam and air, and the heat removed from the generator is accounted for in eight items.

The ratio of the potential heat of the water gas 56 per cent., is a measure of the thermal efficiency of the generator. In determining the efficiency of the whole process, any additional fuel required to raise the steam supplied to the generator and the steam employed in driving the blower must be included. If it be assumed that the steam is raised in independent boilers with an efficiency of 70 per cent., then the overall thermal efficiency of production of water gas would be only 49 per cent. By means of waste-heat boilers, however, a large proportion of the sensible heat of the water gas and the sensible and potential heat of the blow gas can be employed in raising steam, and sufficient steam can be obtained in this manner

to meet the requirements of the generator and auxiliary power. The thermal efficiency of the process is then given by the ratio of the potential heat of the water gas to the heat value of the coke employed in the generator; this efficiency is approximately 60 per cent.

The balance in Table IV. indicates where the heat losses occur in the manufacture of water gas. The greatest individual loss is represented by the potential heat of the blow gas, which accounts for nearly 20 per cent. of the heat supplied. The heat lost as sensible heat in the water gas, blow gas and undecomposed steam, items (2), (3) and (5) was approximately 15 per cent. The utilisation of these amounts of heat in waste heat boilers is extending rapidly, and experience has shown that by this means between 80 and 90 lbs. of steam can be produced per 1,000 cubic feet of water gas made.

CARBURETTED WATER GAS.

The water gas made in the gas works of this country is usually enriched or carburetted by the addition of oil gas before admixture with coal gas for distribution. The oil gas, which is rich in gaseous hydrocarbons, is almost invariably produced by the thermal decomposition or "cracking" of petroleum oil. The "cracking" is brought about by injecting the oil into a carburettor, which consists of a chamber lined with firebrick and filled with chequer bricks heated to between 700 and 800° C. The gases which leave the carburettor then travel through a superheater, which is also filled with heated chequer bricks, but is generally much larger than the carburettor. The main principles of the process may be understood from a description of a typical installation and method of operation.

TABLE IV.—HEAT BALANCE.

Heat supplied:—	Therms per 1,000 c. ft. water gas.	Per cent.		Therms per 1,000 c. ft. water gas.	Per cent.
(a) Coke to generator ...	4.900	92.7	(3) Steam not decomposed (total heat)	0.163	3.1
(b) Steam to generator (total heat)	0.386	7.3	(4) Blow gas, potential heat	1.042	19.7
(c) Sensible heat of air to blower	0.000	0.0	(5) Blow gas, sensible heat...	0.462	8.7
			(6) Ashes, clinker and dust, potential heat	0.294	5.6
	5.286	100.0	(7) Ashes, clinker and dust, sensible heat	0.020	0.4
Accounted for as follows :—			(8) Losses not separately determined (difference) ...	0.174	3.3
(1) Water gas, potential heat	2.960	56.0		5.286	100.0
(2) Water gas, sensible heat	0.171	3.2			

Carburetted water gas plant.

One of the carburetted water gas sets employed by the Joint Gas Research Committee[3] in the investigations carried out at the Windsor Street Works, Birmingham, is shown in section in Fig. 3. This set includes a waste-heat boiler.

The generator is connected by gas off-take pipes, both above and below the fuel bed, with the top of the carburettor. During the blow periods, air enters at the bottom of the generator, and the blast products travel through the outlet pipe at the top and thence through the carburettor, superheater and waste-heat boiler to the stack, which is controlled by a valve at the top. During the run periods, when the blast valve is closed, the steam enters either below or above the fuel bed, and the resultant blue water gas is carried away by the outlet pipe at the top or bottom of the generator according to whether steaming is

[3] Joint Research Committee, Seventh Report, 1922.

being operated in an upward or downward direction. The blue gas is then enriched with oil in the carburettor, whence it passes through the superheater into the wash-box and thence to scrubbers, condensers, tar extractors and purifiers.

The enriching oil is fed into the top of the carburettor during run periods only, through an adjustable spray nozzle. Air valves are provided at the top of the carburettor and the bottom of the superheater for the admission of the requisite quantity of air during the blow periods to burn sufficient gas to heat up the carburettor and superheater to the temperature desired for cracking the enriching oil. The combustible constituents remaining in the blow gas at this stage may be burned by the addition of a further supply of air at the top of the superheater. By this means, potential heat which would otherwise be carried up the stack may be converted into sensible heat and rendered serviceable for raising steam in the waste-heat boiler.

The gas produced during the blow periods passes from the top of the superheater into a brick-lined chamber at the top of the waste-heat boiler. It then travels downwards through steel tubes into a chamber at the bottom of the boiler, whence it enters the stack. The boiler, as is usual in conjunction with water gas sets, is therefore of the fire-tube type, i.e., the hot gas travels through the tubes and the water is on the outside. Waste gas only is allowed to pass through the boiler, which is out of circuit during the run periods when the carburetted gas travels direct from the superheater through a water seal in the wash box. The enriched gas is then cooled by passage through scrubbers and condensers in which water, tar, and an emulsion of tar and water separate out. Some tar remains suspended in a finely divided condition in the gas. It is therefore usual to pass the gas through tar extractors, of which several types are in use, before purification from sulphuretted hydrogen.

In the installation to which Fig. 3 refers, the tar, water and emulsion flow through separating tanks arranged in series. The tar and emulsion are pumped periodically from the separators. Various methods have been tried with the object of breaking the emulsion into its constituents, tar and water, but no method has proved entirely satisfactory in practice.

The largest installation of carburetted water gas sets in this country is that at the Beckton works of the Gas Light and Coke Company. This installation of Humphreys and Glasgow plants has a total capacity of approximately 40 million cubic feet of gas, per day. The valves are operated by hydraulic power, and control levers for each unit are assembled on one bench. The generators are arranged in pairs, so that by the movement of one lever the generators may be set for operation during the run periods, either in series or in parallel.

In some types of water gas plant the carburettor and superheater are combined in one chamber of somewhat larger capacity than the superheater of the more usual plant, and the method of injection of the oil varies. For example, in the Merrifield-Westcott-Pearson plant the oil is injected at several points in a direction opposed to that in which the stream of gas is travelling.

A recent introduction in the method of operation, known as the back-run process, consists of passing steam during part of the run in a reverse direction to the generator through the superheater and carburettor. This superheats the steam and reduces the coke consumption in the generator, but also reduces the heat available for the waste-heat boiler.

Carburetted water gas plants may also be utilised for the manufacture of blue water gas, in which case no enriching oil is employed.

Results of operation.

As in the production of blue water gas, the best conditions for the manufacture of the enriched gas vary according to the type and size of installation and the coke available. In addition, the nature and quantity of enriching oil employed must be taken into account in determining the best temperature for the cracking process.

The averages of the principal results obtained during the investigation mentioned are given in Table V.

TABLE V.—RESULTS PER 1,000 CUBIC FEET CARBURETTED GAS MADE.

Coke (dry; 11.2 per cent. ash) to generator, lbs.	35.7
Oil to carburettor, gallons	1.84
Blue water gas, cubic feet	840
Oil gas, cubic feet	160
Calorific value (gross) blue water gas, B.Th.U. per cu. ft.	292
Calorific value (gross) carburetted gas, B.Th.U. per cu. ft.	483
Steam raised in waste-heat boiler, equivalent evaporation from and at 100° C., lbs.	73

From the figures given in the table it can readily be calculated that the enrichment resulting from the carburetting process was equivalent to approximately 100 B.Th.U. per cubic foot, per gallon of oil, per 1,000 cubic feet of water gas made, and that each gallon of oil produced about 90 cubic feet of oil gas. In other words, 910 cubic feet of blue water gas of a calorific value of 300 B.Th.U. per cubic foot, when enriched by one gallon of oil, would produce 1,000 cubic feet of a gas of 400 B.Th.U. per cubic foot. This is equivalent to an enriching power of nearly 1.3 therms per gallon of oil. The amount of good tar produced was approximately 12 gallons per 100 gallons of oil, and in addition the emulsion contained about three gallons of tar. The amount of water evaporated in the waste-heat boiler was sufficient to meet the steam requirements of the generator, turbo-blower, exhauster, oil pump, and boiler feed pump.

TABLE VI.—COMPOSITION OF GASES, VOLUMES PER CENT.

	Blue water gas.	Carburetted water gas.	Blow gas leaving generator.	Waste gas leaving boiler.
CO_2	6.1	5.3	11.8	16.8
C_mH_n	0.0	5.9	0.0	0.0
O_2	0.1	0.3	0.1	0.8
CO	38.4	34.7	14.1	3.4
H_2	51.6	38.3	2.7	1.1
CH_4	0.5	10.0	0.2	0.4
N_2	3.3	5.5	71.1	77.5
	100.0	100.0	100.0	100.0

The average compositions of the gases produced during the tests are given in Table VI.

The composition and calorific value of carburetted water gas vary according to the amount of enriching oil used; the figures in Table VI. represent a gas of a calorific value of 483 B.Th.U. per cubic foot. The waste gas contained carbon monoxide and hydrogen although free oxygen was present. Improvements, however, are now being made to ensure better combustion of the blow gas and less loss of potential heat in the waste gas.

Thermal efficiency.

Heat balances in therms per 1,000 cubic feet of carburetted gas made of a calorific value of 483 B.Th.U. per cubic foot, and in percentages under the conditions of the tests by the Joint Gas Research Committee are set out in Table VII. It may be calculated from the figures in this table that the thermal efficiency of the whole process of manufacture of carburetted water gas of a calorific value of 483 B.Th.U. gross, taking into account the steam required for the generators and auxiliary power and crediting the process with the steam raised in the waste-heat boiler, is approximately 68 per cent. The potential heat values of the oil gas and tar produced were respectively 77 per cent. and 16 per cent. of the heat value of the oil employed. It is this high efficiency of the " cracking " process which caused the efficiency of the whole process to be so high as 68 per cent. It is necessary, therefore, in stating the efficiency of production of carburetted water gas to state the quality of gas produced, for the overall efficiency is dependent on the amount of oil gas admixed with the blue water gas.

TABLE VII.—HEAT BALANCE IN PRODUCTION OF CARBURETTED WATER GAS.

	Therms per 1,000 c. ft C.W. gas made.	Per cent.
Heat supplied:—		
(a) Coke to generator	4.599	59.7
(b) Oil to carburettor	3.092	40.2
(c) Sensible heat of air to blower	0.004	0.1
	7.695	100.0
Accounted for as follows:—		
1. Carburetted water gas, potential heat	4.830	62.8
2. Carburetted water gas, sensible heat	0.318	4.1
3. Steam not decomposed, total heat	0.156	2.0
4. Tar, potential heat	0.519	6.7
5. Tar, sensible heat	0.022	0.3
6. Waste gas, potential heat	0.505	6.6
7. Waste gas, sensible heat	0.327	4.2
*8. Heat to raise steam in waste-heat boiler	0.381	5.0
9. Heat supplied to water "blown off" from boiler	0.004	0.1
10. Ashes and clinker, potential heat...	0.319	4.1
11. Ashes and clinker, sensible heat	0.016	0.2
12. Losses not separately determined	0.298	3.9
	7.695	100.0

OTHER SUPPLEMENTARY GAS-MAKING PROCESSES.

In addition to the manufacture of blue and carburetted water gas for admixture with coal gas made in retort systems, a large number of supplementary gas-making processes have been introduced during recent years. In general these supplementary processes might be described as modifications of water gas practice, and the main development has been in the direction of the complete gasification of coal in one apparatus. The many processes designed are too numerous to be considered in any detail, but a brief description of some typical processes illustrative of general principles will be given.

Complete gasification.†

The gasification of coal can be secured in two stages, by first carbonising coal by usual methods and then utilising the whole of the available coke produced for the manufacture of water gas in a separate installation, the only material not converted into gas being the tar obtained during carbonisation.

With the object of obtaining certain improvements, various systems have been designed, and some have been operated on a commercial scale for the more complete gasification of coal in one plant. The general principle underlying such systems is that the heat of the gases produced during the manufacture of blue water gas by the intermittent process is utilised for the purpose of carbonising coal in some form of retort in connection with the water gas generator. In a single stage process of this type the coke passes in a heated condition direct from the retort to the generator, and in addition the consumption of the coke ordinarily required for heating the retorts of usual carbonisation systems is avoided. On the other hand, the temperature attained by the coal in the retort cannot be so high as in ordinary retort practice, with the result that unless special provision is made the coke entering the generator contains valuable gas which

*This figure in item 8 represents the total heat of the steam raised in excess of that required for the generator. The total heat of the steam supplied to the generator is not included, since in such case it would be necessary to include it also in the heat supplied.

†The complete gasification of coal may be obtained by the manufacture of semi-water gas and producer gas, but these gases are not considered suitable for admixture in large quantities with coal gas for general supply, since they contain from 45 to 60 per cent. of nitrogen, and their calorific values, 130 to 160 B.Th.U. per cubic foot, are low.

must in large measure be carried away with the waste gases during the blow periods. In several systems, in addition to the heating of the retort externally by the combustion of blow gas, hot water gas is passed through the retort and this might result in more rapid transmission of heat to the charge undergoing carbonisation. If heat from the generator is usefully employed in the carbonisation of coal however less heat will be available for steam raising in waste-heat boilers. Although several varieties of single-stage process combining coal carbonisation and water gas production are in operation, the published results of tests have not been sufficiently comprehensive to enable the construction of thermal balances.

In Robinson's mixed gas plant as developed and operated at the gas works, Harrogate, the producer of a setting of horizontal retorts is replaced by a water gas generator. The retorts are heated externally by the combustion of blow gas and air. The blue water gas made during the run periods passes from the generator into the retorts, travels over the charges undergoing carbonisation and the resultant mixture of water gas and coal gas enters the hydraulic main to mix with coal gas from retort settings of usual type.

The Tully gas plant, a number of which are in operation in this country, is an example of the type of process in which a vertical retort is superimposed on a water gas generator. During the blow periods, air is admitted at the base of the generator, and the blow gas leaves the top of the generator section to enter combustion chambers surrounding the retort. The potential heat of the blow gas is liberated by the admission of secondary air to the combustion chambers which contain chequer brickwork. In this manner the retort is heated externally. When the steaming operation is carried out in an upward direction, the steam enters the base of the generator and the blue water gas produced travels upwards through the retort to assist in the carbonisation of the coal.

The Kramer and Aarts water gas plant, as modified by H. E. Smith, is designed for the gasification of coal or coke, and means are provided for the enrichment of the gas with oil if required. This plant, Fig. 4, consists of a steel shell containing two generators each of which is surrounded in the upper tapered portion by a regenerator. The coal to be gasified is supplied at the top through two automatic feed hoppers. The lower sections of the generators are air-blown in parallel and the blow gases are burned in the regenerators to heat the upper portions and carbonise the coal. The steam admitted during a run period passes downwards through one regenerator, travels in series through the lower generators containing coke, and finally upwards through the fuel undergoing carbonisation in the upper part of the second generator.

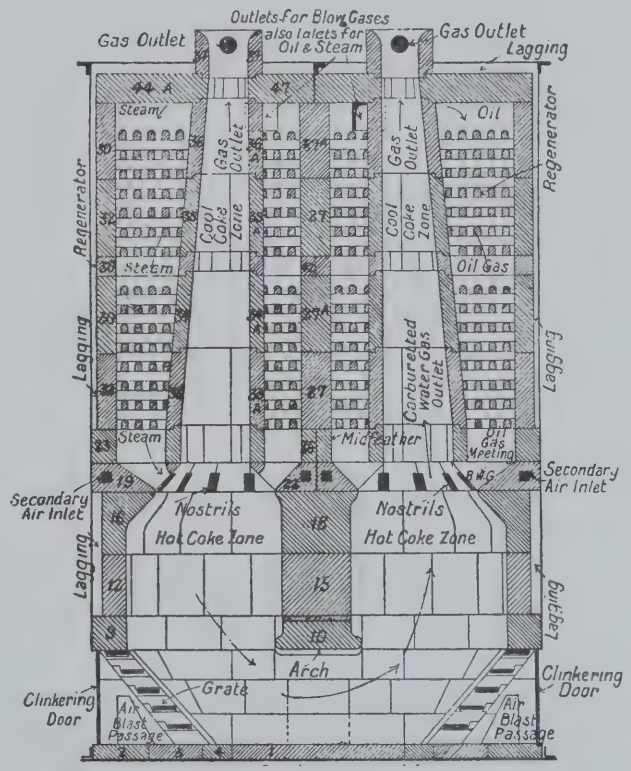

FIG. 4.—*Smith's modification of Kramer and Aarts Plant.*

The Travers-Clark regenerative coal gasification system as installed at Aylesbury, presents several novel features. In the lower portion or gasification section of the generator, A, Fig. 5, coke produced by the carbonisation of coal in the upper section is converted into water gas. At a level intermediate between the carbonisation and gasification sections, a circular channel communicates with a separate regenerator. During the blow, air enters below the grate of the generator and the blow gas passes through the regenerator. Secondary air is admitted to the regenerator to burn the blow gas. When steam is admitted at the base of the generator, the water gas produced travels upwards through the carbonisation zone, the mixed gas leaving at the top to pass through a wash-box, a scrubber and a condenser. At the same time, mixed gas, drawn from the main at the outlet of the scrubber, is circulated through the

regenerator, where it is raised to a temperature of about 850° C. and passed through the carbonisation section of the generator. The carbonisation is thus achieved by the transference to the coal of the sensible heat of gas preheated by the combustion of blow gas in the regenerator. External heating of the carbonisation section is not employed. During down runs, the steam is preheated in the regenerator before passing to the gasification zone.

Several plants have been designed in which " tri-gas," which is a mixture of producer gas, water gas and coal gas, is produced during the gasification of coal. The Dellwik-Fleischer tri-gas system, which has been operated on the Continent, consists of a producer in the base of which a mixture of water gas and producer gas is manufactured and is passed through a superimposed column of coal. The coke in the lower section is first raised to a high temperature by the admission of air, and the blow gas produced leaves the plant at the top of the coke zone and below the carbonisation zone. Superheated steam is then admitted to the lower section and a proportion of superheated air is also supplied to ensure that the gaseous mixture is at a sufficiently high temperature to carbonise the coal in the upper portion. The carbonisation section is not heated externally, internal heating only being employed.

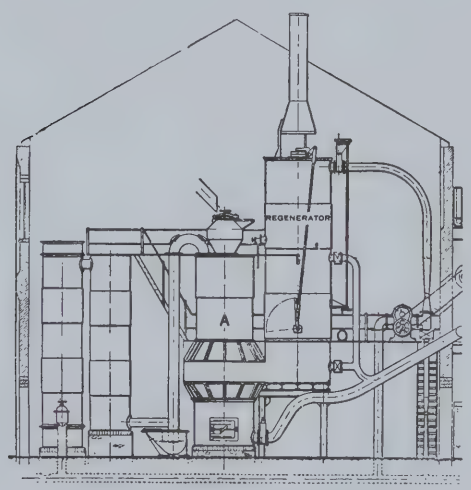

FIG. 5.—*Travers-Clark Gasification System.*

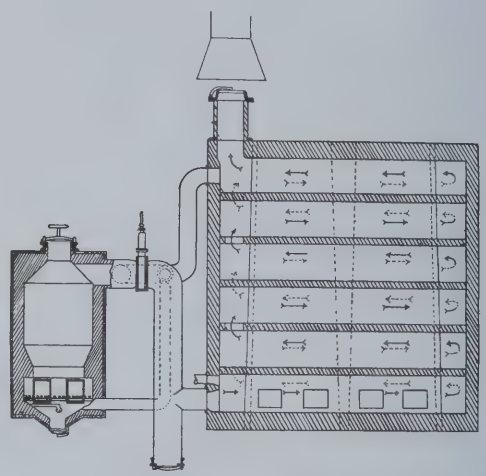

FIG. 6.—*Parker's Mixed Gas Plant.*

The author has designed a system,[4] Fig. 6, for the purpose of producing a mixture of water gas and coal gas in one apparatus. The plant consists of a water gas generator and a setting of vertical retorts. During the blow periods, the blow gas leaves the top of the generator and enters the combustion chambers surrounding the retorts at the bottom of the setting. Secondary air is admitted to the combustion chambers to burn the blow gas and raise the temperature of the retorts. The burning gases travel around the retorts. The waste gases leave the combustion chambers by way of a stack at the top, or they may be utilised for the production of steam in waste-heat boilers. The water gas made during the run periods enters the combustion chambers near the top of the setting, and travels in a direction the reverse of that previously taken by the blow gas. The water gas thus preheated passes into the retorts, and travels upwards through the coal undergoing carbonisation. The coal is thus carbonised by direct contact with preheated water gas, and in addition the retorts are heated externally by the combustion of blow gas. The coke produced is withdrawn from the lower ends of the retorts. The main object of the invention is to produce a smokeless fuel of uniform quality and suitable for domestic purposes. The coke required by the generator may be obtained from the retorts of the plant, or other coke may be employed. By suitable regulation of the rate of supply of coal to the retorts, it may be arranged that the amount of coke withdrawn exactly meets the requirements of the generator, when the process is one of complete gasification. The invention includes an arrangement to prevent the loss of coal distillation products during blow periods.

[4]E.P., 255, 279.

Future developments.

It is probable that water gas plants or modifications of the type indicated in this chapter will be used for many years as supplementary processes in the manufacture of gas for town supply.

The utilisation of the sensible heat of water gas and the potential heat of blow gas in the water gas process for raising steam, has proved a distinct advance in the direction of fuel economy. Waste heat boilers for this purpose are now established as a commercial proposition, and it would appear that their erection in conjunction with water gas plants is rapidly becoming almost standard practice.

It is difficult to foresee any single improvement which will prove so great a step forward as that gained by the introduction of waste heat recovery in boilers, but there is no doubt that advances can be made. The next step of importance is to provide means for supplying air to the generator with a much smaller consumption of steam. Much can be achieved by the extended use of electrical power in place of the very inefficient non-condensing turbines at present driving the blowers of many installations, especially in large works where electricity is required for many purposes, and can be generated by more efficient and larger turbines of the condensing type. The steam requirements of water gas plant might also be reduced to a small extent by the utilisation of some waste heat for superheating the steam supplied to the generator. The reduction in steam requirement would result in more steam being raised in the waste heat boiler than necessary for the generator and auxiliary power, but the surplus could generally be usefully employed for other purposes in gas works practice. Another step in the direction of fuel economy would be to recover the valuable fuel withdrawn with the ashes and clinker, as is already done in a few instances. The operation of clinkering should be completed as rapidly as possible to ensure that the combustion of coke during the process is reduced to the minimum.

In the carburetted water gas process, a reliable system for the prevention of the formation of an emulsion of tar and water is required to enable the recovery of the whole of the tar.

In several large installations labour charges have been reduced by the use of hydraulic power for operating the valves, by automatic control and by the installation of mechanical grates. Further application of labour-saving devices is likely to occur. In addition, the growth of scientific methods in the measurement of fuel, air and steam and in plant control is certain to result in a higher average efficiency throughout the country.

In those processes in which the heat of the gases produced in the manufacture of water gas is utilised for the carbonisation of coal, the waste gases must carry away appreciable quantities of heat since the carbonisation requires a comparatively high temperature. If high efficiencies are to be obtained therefore further heat utilisation, as in waste heat boilers, is required. The recent developments have been towards the complete gasification of coal, but the author is of the opinion that developments may be expected in the direction of the carbonisation of coal by preheated water gas for the manufacture of smokeless fuel, a portion only of the coke being used in the water gas generator.

Finally, mention must be made of the possibility of the gasification of coal or coke by a continuous process employing a mixture of oxygen and steam. The success of a process of this kind which should thermally be very efficient, is dependent on the production of oxygen at a price very much lower than is possible at present.

Chapter 4.

THE USE OF TOWN'S GAS IN INDUSTRY.

By Percy Hopkinson.

Previous to 1875 very little of the town's gas generated was used for industrial purposes, its use being confined almost solely to illumination purposes.

The increase in the use of gas in industry during recent years has been most striking, and some idea of the extent to which gas is used as a fuel may be gathered from the fact that about 3,000 distinct trades use this form of fuel for an average of seven processes in each.

From statistics relating to the gas industry it is noted that the average annual growth in consumption has been :—

Years 1894—1904	5,042	million cubic feet.
Years 1904—1913	5,655	„ „
Years 1913—1925	4,940	„ „

A supply of gas is available to 95 per cent. of the population, and the reliability of supply may be appreciated when it is stated that the gas service to London has not been interrupted during the past 114 years.

During 1925 the gas industry used 17,798,725 tons of coal, from which was produced over 273,432 million cubic feet of gas, over 8½ million tons of coke, 201 million gallons of tar, or tar products, and 171,000 tons of sulphate of ammonia. The average consumption per consumer per annum during 1925 was 31,500 cubic feet.

The extent to which gas is used in certain towns for industrial purposes is indicated in the following figures :—

Coventry. The total quantity of gas sold in the area of supply during the year ending March 31st, 1926, was 2,187,672,300 cubic feet, and of this total 42 per cent. was used for industrial purposes. Its application was for the heat treatment of metals and other processes in connection with the motor car industry.

Glasgow. During the period of 1925-6 the amount of gas used for manufacturing purposes only amounted to 972,614,900 cubic feet, representing 10.68 per cent. of the gross sales. For the same period the amount of gas used for power purposes only, amounted to 148,294,300 cubic feet, or 1.623 per cent. of the gross sales.

Birmingham. The annual sales of gas in the Birmingham area of supply now amount to over 13,000 million cubic feet of which more than 2,600 million cubic feet are used for manufacturing purposes as distinct from power purposes. Thus over 20 per cent. of the output of the Birmingham Gas Department is used for industrial purposes.

Greenock. The amount of gas used in the Greenock area of supply for industrial purposes during the year 1926-27 was 52½ million cubic feet, being equal to 8.7 per cent. of the total gas sold.

The great limitation under which gas undertakings are operating to-day with regard to the increase in sales of gas for industrial purposes is due to the factor of cost. At the same time bare fuel costs should not be determining factors in influencing fuel selection. The question of rates for industrial gas requires careful consideration by gas undertakings wishing to obtain this desirable load. The industrial consumer invariably pays a price for the gas used far in excess of what it costs to supply, or in other words, the costs involved by the gas company are not distributed over the various classes of customers in an equitable manner.

The only fair method of selling gas is to charge each consumer in proportion to what it costs the gas undertaking to provide him with the service, plus a fair and reasonable return on the same.

In making an analysis of the cost of supplying gas to consumers, it is found that the various factors of costs can be placed under three main heads.

The first of these may be termed the "Customer Cost," under which falls the periodical bills, reading of the meter, the making out of and the keeping of accounts which necessitates an office staff; the second may be described as the "Demand Cost," representing in general that cost item involved by the gas undertaking in being ready at all times to supply the maximum hourly demand of the consumer; the third cost is that of manufacturing and distributing the gas to the consumer, and may be described as the "Consumption Charge."

The consideration of gas charges under these three heads is described as the "three-part" rate, and has been discussed exhaustively by the American Gas Association during the last few years.

The report of the Rate Structure Committee shows that in general the expenses of a large gas undertaking can be approximately distributed as follows:—25 per cent. Customer Cost; 25 per cent. Demand Cost; 50 per cent. Consumption Charge.

With smaller undertakings the cost allocation is more in the region of one-third of the total cost to each of the three items. On this basis of charging for gas it is obvious that in the case of an undertaking having a large consumer of gas for industrial purposes with a good load factor, the items of "customer cost" and "demand cost" become very small in proportion to the total charge, and this will be only slightly greater than the "consumption charge."

Under the three-part rate method of charging for gas, the "Customer Charge" is the same for all customers, irrespective of whether they are large users or small users, or use no gas whatever. This is an annual charge, but is divided into quarterly or monthly amounts as the case may be. The "Demand Charge" is also an annual charge and is in proportion to the customer's maximum hourly demand. The "Consumption Charge" is uniform per 1,000 cubic feet for all consumers, irrespective of the amount of gas used.

Using assumed figures the three-part rate would work out as follows for different consumers. The assumed figures will be: Customer's charge, £2 10s. per year; Demand charge (based on 50 cubic feet per hour maximum demand and 1s. 4d. per cubic foot of maximum hourly demand) will be £3 6s. 8d. per year; and Consumption charge, at the rate of 1s. 3d. per 1,000 cubic feet.

In the case of the first customer it will be assumed that no gas is consumed, and therefore the charge per month would be:—

	£	s.	d.
Customer cost	0	4	2
Demand cost	0	5	7½
Total	£0	9	9½

Although the customer has used no gas he has involved the gas undertaking in the expenses mentioned, so the charge stated would be both just and reasonable.

Assuming that a customer, having the same maximum hourly demand of 50 cubic feet, consumed 1,000 cubic feet per month, then his charge would be as follows:—

	£	s.	d.
Customer cost	0	4	2
Demand cost	0	5	7½
Consumption charge	0	1	3
Total	£0	11	0½

This customer would pay at the rate of 11s. 0½d. per 1,000 cubic feet, which may appear high but is quite fair as the expense to the undertaking has been correctly proportioned.

A further consumer having a maximum hourly demand of say 125 cubic feet per hour and a monthly consumption of 20,000 cubic feet, would be charged:—

	£	s.	d.
Customer cost	0	4	2
Demand cost	0	13	10½
Consumption charge	1	5	0
Total	2	3	0½

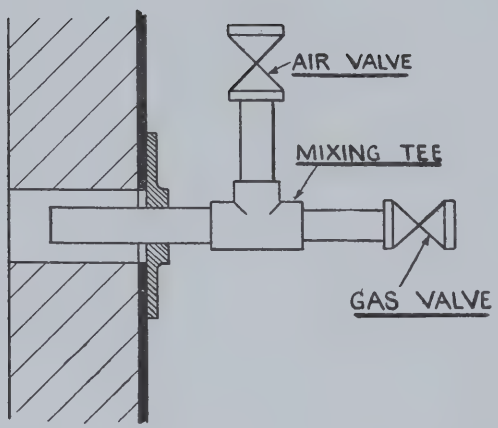

Fig. 1.

This customer would be paying at the rate of approximately 2s. 1¾d. per 1,000 cubic feet, which although low compared with the previous examples is quite fair as the customer is paying the undertaking for exactly what is received.

In the case of a large industrial consumer with a demand of 10,000 cubic feet per hour, and a monthly consumption of say 6,000,000 cubic feet, his bill would amount to :—

	£	s.	d.
Customer cost	0	4	2
Demand cost	55	11	0
Consumption charge	375	0	0
Total	£430	15	2

This large industrial consumer would be paying at the rate of 1s. 5¼d. per 1,000 cubic feet, at which price gas with its many advantages would compare favourably with other fuels.

The figures quoted are simply for the purpose of showing the basis for a gas charge on a three-part rate, and may need considerable adjustment to meet a specific case.

From the examples given it will be realised that a straight gas charge per 1,000 cubic feet, or per therm, as the case may be, would be unfair to the large consumer, as the profits obtained by the gas undertaking from this consumer must go to balance the deficit from the small consumer.

A charge for gas made up on the three-part rate offers an inducement to industrial concerns to take up this form of fuel, and the gas undertaking obtains a fair return on the expense involved in supplying a large customer, even though the price charged for the gas may only be a fraction of that charged to the domestic consumer.

Qualities of town's gas available.

The advance in the science and practice of gas manufacture during the last 20 years has been very great, and one of the most important steps towards coal conservation and by-product recovery has been due to the abolition of the antiquated candle-power standard of gas quality.

With the introduction of the incandescent gas burner for lighting the necessity for a gas containing valuable hydrocarbons and having a high calorific value failed to exist.

What is required to-day either for illumination purposes or for the needs of industry is a gas containing desirable qualities of flame temperature, flame propagation and chemical composition. The gas

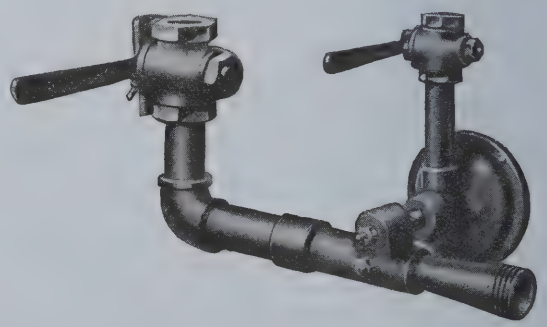

Fig. 2.—*Standard Single Stage Low-pressure Proportioning Inspirator, with Governor.*

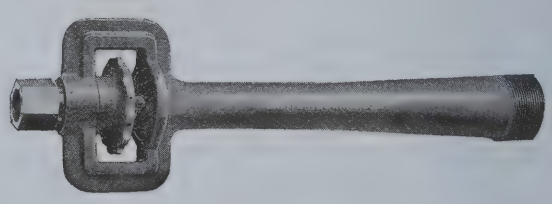

Fig. 3.—*Standard High-pressure Inspirator.*

should be devoid of hydrocarbons, of high flame temperature and non-luminous in a flat flame burner. A gas possessing these features allows gas undertakings to manufacture the maximum volume of gas per ton of coal carbonised, and also to recover as far as possible the valuable by-products so vital to the needs of the country.

A gas can be readily manufactured containing between 350 and 400 B.Th.U.'s per cubic foot which would be entirely suitable for illumination and industrial purposes, and even superior to the 550 to 600 B.Th.U. gas manufactured in the past. With the lower calorific values mentioned the yield of gas would range from 15,000 to 25,000 cubic feet per ton of coal carbonised, with an increased yield of by-products.

At the present time gas qualities vary between wide limits in the various cities and towns in the United Kingdom, and Table I. gives typical analyses of different qualities of town's gas available.

TABLE I.—TYPICAL ANALYSES OF TOWN'S GAS (PERCENTAGES).

	1	2	3	4	5	6	7
CO_2	1.4	1.8	2.4	3.5	4.5	5.5	6.6
CnHm	3.2	2.2	2.2	1.7	1.8	1.7	1.6
O_2	0.2	0.6	0.7	0.6	0.3	0.6	1.0
CO	6.9	7.4	11.3	15.5	17.8	19.8	17.9
H_2	50.1	52.0	49.6	50.7	51.6	49.3	48.3
CH_4	29.9	29.0	25.9	21.0	18.0	16.4	14.5
N_2	8.3	7.0	7.9	7.0	6.0	6.7	10.1
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

It is of the greatest importance that gas quality should be standardised from the point of view of the gas undertaking, the consumer, and also the furnace manufacturer. Such a standardisation would allow appliance manufacturers to standardise their products and make for higher efficiency in combustion, and production of combustion appliances.

Coal gas is a mixture of known gases, and with the composition known, the amount of oxygen required for complete combustion can be calculated together with the resultant products. The theoretical mixture of air and gas will give the maximum flame temperatures which can be calculated from the known specific heats of the gas. Excess of gas or air reduces flame temperature. The fundamental requirement of all heating systems, if maximum efficiency is to be obtained, is that they shall be provided with automatic proportioning of air and gas, in order to assure maximum flame temperatures without frequent adjustment.

GAS BURNING SYSTEMS.

Atmospheric. For processes requiring a working temperature up to 600° C. and where an ample supply of secondary air can be assured atmospheric burners can be successfully applied. This type of burner is simple and cheap to install, as only a gas connection is required and no other auxiliary equipment is necessary.

Atmospheric burners should not be installed where flames are required to burn in a space through which products of combustion from other flames are passing. Where possible the burner ports should be drilled in raised teats and each individual port should be arranged so that secondary air is accessible all round.

The burner should be placed as close to the appliance being heated as possible without causing the flames to impinge and also without causing floating from the banking of products of combustion over the burner. The position of the burner must be such that a free exit is allowed for the burned gases.

The draught in a furnace heated by means of an atmospheric burner should be adjusted to show a slight percentage of oxygen in the products of combustion when the burner is operating at full capacity.

An atmospheric burner consists essentially of three parts, a gas orifice, air mixer and the burner proper. The function of the air mixer is to draw in sufficient air for complete combustion by utilising the velocity of the gas issuing from the gas orifice. The higher the velocity of the gas issuing from the orifice the greater will be the amount of air entrained. Average quality town's gas requires about five volumes of air to one of gas for complete combustion, but with atmospheric burners operating at ordinary town's distribution pressure the air-gas rate in the burner chamber is about three to one. The remainder of the air for complete combustion must be supplied through the medium of chimney pull. The air entrained through the mixing tube is thoroughly mixed with the gas, which condition is essential for good combustion, whereas the secondary air is not mixed and therefore must be supplied in considerable excess to ensure complete combustion. In atmospheric burners the primary air-gas ratio should be as high as possible and the secondary air requirements as low as possible.

The following conditions are essential in atmospheric burners to ensure perfect combustion :— 1. The aeration of the burner must be such that there is enough primary and secondary air available to prevent the formation of any carbon monoxide. 2. The maximum amount of air for combustion should be supplied as primary air. 3. The flames should not leave the burner ports. 4. The flames must not light back into the mixing tube.

Air Blast Systems. Where a higher temperature is required than can be obtained with atmospheric burners, the simplest system to adopt consists of independently controlled gas and air pipes leading to a

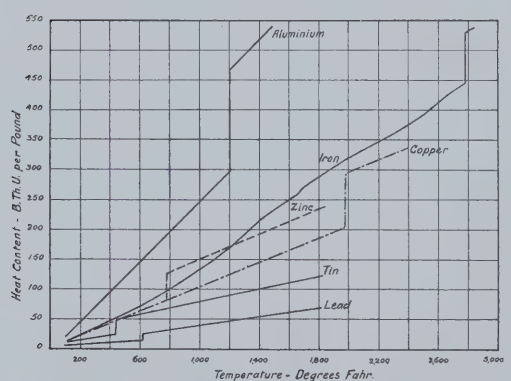

FIG. 4.—*Heat Contents of Pure Metals at Various Temperatures.*

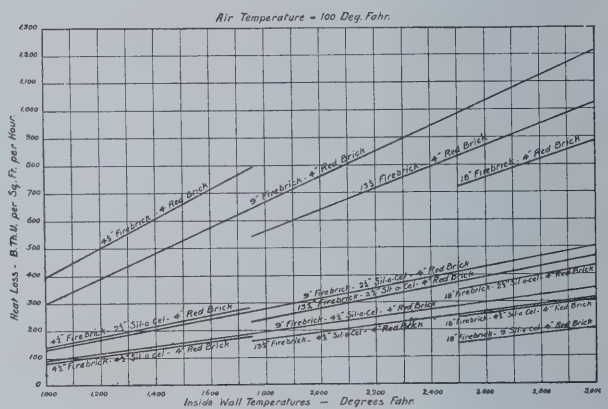

FIG. 5.—*Heat Losses through Insulated and Uninsulated Walls of typical thicknesses.*

mixing tee and from this tee the mixture of gas and air is carried to the burner, or burners by a single pipe. The gas is usually under ordinary town's distribution pressure and the air supply at a pressure from $\frac{1}{4}$ lb. per sq. in. or upwards. The equipment is shown diagrammatically in Fig. 1. This system gives an intimate mixture of the gas and air, and this fact assists in obtaining high temperatures. Any variations of the gas or air pressure materially change the mixture proportions and therefore the furnace atmosphere, so vital to some heating operations, cannot be accurately controlled. With this system a slight back pressure can be carried in the combustion chamber, and combustion can be maintained in an atmosphere which will not support combustion.

The application of thermostatic control to furnaces fitted with this system is complicated as two valves, one for air and one for gas, have to be operated. The two-valve control air pressure combustion system is not to be recommended, unless the appliances are small and the gas consumption low.

The alternative to the system above is one using air under a pressure of $\frac{1}{2}$ lb., per sq. in. or over together with gas at town's distribution pressure, but which allows of automatic proportioning and single valve control.

The feature of automatic proportioning ensures that the ratio of air to gas in the mixture supplied to the burner, or burners, is maintained at all rates of consumption without attention on the part of the

operator, and in addition this ratio is independent of variations in the pressures of the respective supplies of gas and air.

The mixture of gas and air, when using the automatic proportioning system, is in a thoroughly homogeneous condition. This condition is an ideal one in which to discharge a mixture from a burner

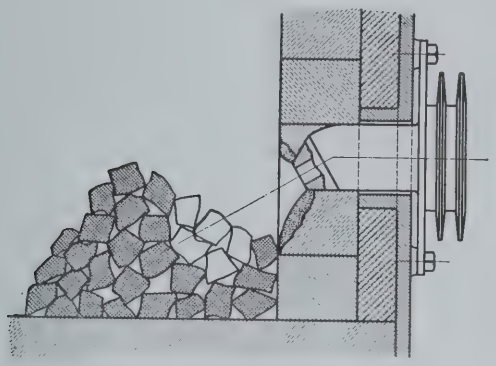

FIG. 6.—*Impact Type Burner Using Refractory Bed Type.*

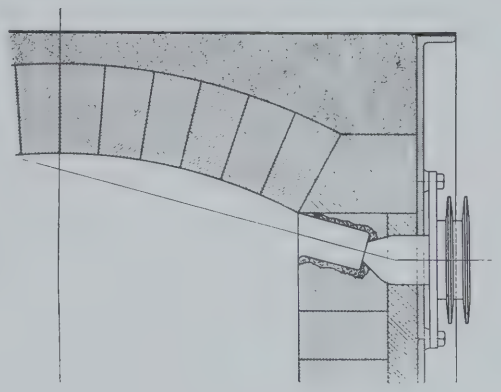

FIG. 7.

nozzle, because combustion will be instantaneous and complete and a minimum size of combustion chamber will be required. Whilst it is important that the mixture be correctly proportioned, it is almost as important that it be thoroughly homogeneous.

The operating principle behind the automatic proportioner is that the energy of a stream of air passing through a tube of venturi form is utilised to entrain gas which has been reduced to atmospheric pressure by means of a suitable governor. The amount of gas entrained depends on the amount of air passing through the venturi tube and therefore it is only necessary to operate the air control valve on a furnace equipped with an automatic proportioning burner system. Independent means are provided on the proportioners for setting the air-gas ratio to suit desired furnace conditions with regard to atmosphere. High burner pressures are possible with this system giving wide ranges of consumption with a given apparatus, and as the homogeneous air-gas mixture is forced through the burner orifices at a greater rate than that of flame propagation, lighting back is eliminated.

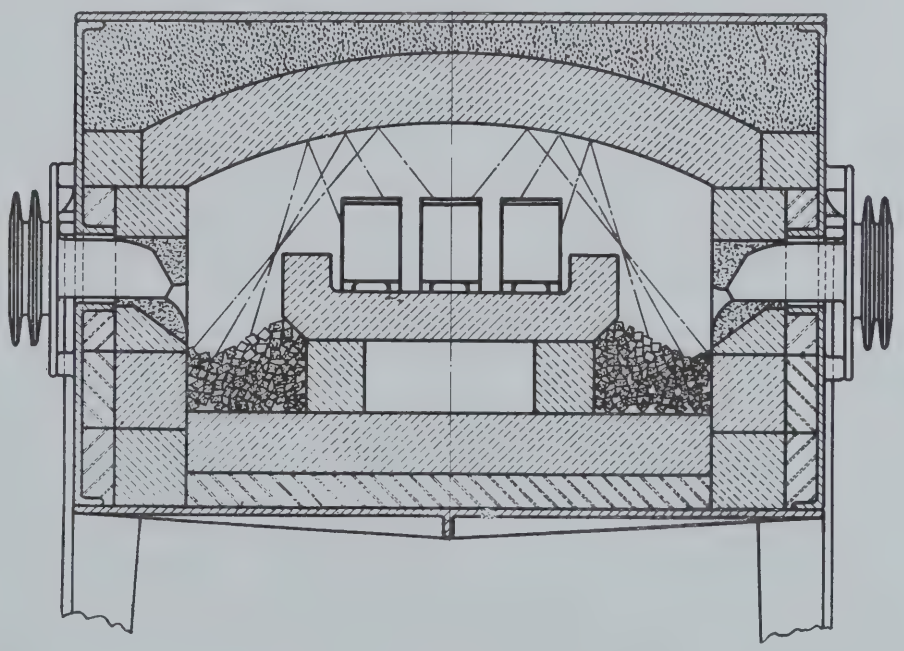

FIG. 8.

A typical air-gas proportioner is illustrated in Fig. 2.

High Pressure Gas. For use with town's gas at pressures of 2 lbs. per sq. in. or over, a simple automatic proportioning combustion system is available which gives one-valve control. Gas issuing at high velocity from a jet at the entrance to a venturi form of throat entrains from the atmosphere the correct amount of gas for perfect combustion. The correctly proportioned mixture of gas and air in a thoroughly mixed condition is delivered to the burner, or burners, under a high burner pressure causing a high velocity through the burner ports, thus preventing lighting back. The air-gas ratio in the mixture is determined by the size of the jet through which the gas issues.

The high pressure gas system requires only one pipe of small diameter to carry the gas and no air is necessary. An air gas proportioner of the high pressure gas type is illustrated in Fig. 3, whilst Table II. is indicative of the capabilities of this form of apparatus as to automatic proportioning.

TABLE II.

Gas used—Mixed Gas, 533.5 B.Th.U.'s; Theoretical Oxygen required in mixture = 17.07 per cent.; Theoretical carbon dioxide formed = 16.2 per cent.

Run No.	1	2	3	4	5	6
Gas Pressure at orifice, lbs./sq. in.	9.38	7.44	5.89	4.74	2.90	1.12
Mixture pressure at burner, ins. of water	4.4	3.6	2.8	2.3	1.35	0.50
Rate of gas consumption, cu. ft. per hour	481.0	438.0	375.0	333.0	254.0	164.0
Percentage of rate at first run	100.0	91.0	77.9	69.2	53.0	34.0
Percentage of oxygen in mixture	17.10	17.00	17.05	16.97	16.88	16.86
Percentage of required theoretical oxygen	100.17	99.59	99.88	99.41	98.88	98.77

The apparent temperature in the furnaces varied from 2550° F. (1400° C.) after run No. 1, to 2250° F. (1230° C.) after run No. 6. The true temperature was somewhat higher as soft iron wire melted quite readily during No. 1. The carbon dioxide with furnace top open = 14.8—15.2 per cent. With furnace top closed = 16.1 per cent.

High Pressure Mixture. With this system a mixture of gas and air is delivered from a compressor through a single pipe connection. The amount of air admitted to the compressor is less than that required for perfect combustion, and the remaining air for combustion is drawn in at the burners. The amount of the latter thus depends on the draught in the furnace and the amount of opening of the air shutter.

Recuperation and Regeneration. In the combustion of town's gas a considerable amount of the heat generated by burning the gas is lost in the waste gases of an ordinary furnace, unless means are taken to recover this. The higher the working temperature of the furnace the greater will be the percentage of sensible heat carried away by the flue gases. Until recent years the utilisation of the heat contained in the flue gases has not been given the amount of consideration it deserves, but high fuel prices and decreasing fuel reserves have contributed to making manufacturers realise the importance and necessity of utilising this heat. The methods of using the heat contained in waste furnace gases may be placed under two general heads, preheating the working material and preheating the gas or air necessary for combustion. The best form of heat transfer is by means of the counter-current flow, in which the material being heated passes through the furnace in the opposite direction to the flow of hot gases. In continuous furnaces of this type gas is burned at one end and the flue gases leave at the other, while the material to be heated enters at the end from which the products of combustion escape and travels to the hottest or combustion end. The speed of travel is arranged to bring the material to the required temperature during its passage through the furnace.

The utilisation of the heat in the waste gases to preheat the gas or air for combustion, is effected in two general types of apparatus recuperators and regenerators.

For small and medium sized installations it is advantageous to use recuperation, owing to the lower first cost and compact form in which recuperators can be built. Recuperators consist of a nest of tubes placed in the flue gas passage and through which the air for combustion passes. Preheating of the air occurs by transfer of the heat from the hot flue gases through the tube walls, and by using counter current flow, a large percentage of heat can be transferred from the flue gases to the air.

Early forms of recuperators were made from sheet iron or steel but for temperatures above 400° C., these have a very short life. The advent of chrome steels and nickel-chromium alloys has made possible the use of metallic recuperators for temperatures up to 1,000° C. Metal recuperators most nearly approach the ideal form of preheating device as they are compact, have a high rate of heat transmission with a small temperature loss, and can be used for long periods while still remaining gas and air tight. The material from which the tubes are made is non-porous and due to its high mechanical strength allows of the use of thin partitions or walls. The flow of air through recuperators is continuous and no change-over gear is necessary.

Regenerators consist of two large chambers usually filled with chequer brickwork and provided with valves, so that the air to be heated and the waste gases can be passed through alternately. Whilst the flue gases are heating up the chequer bricks in one chamber, the air to be preheated is passed through the other where it absorbs the heat from the brickwork. Regenerators permit of high degrees of preheat but are bulky, expensive both to build and maintain, and require constant attention for changing over the flow of gas and air.

Regenerative furnaces are not so suitable for intermittent works as recuperative furnaces owing to the large heat capacity of the regenerators.

FACTORS IN FURNACE DESIGN.

The disposal of the heat supplied to a furnace may be dealt with under three heads: (1) Heat absorbed by the material being heated; (2) heat lost through the furnace walls; (3) heat carried away in the waste gases.

These items will be dealt with in detail as they constitute the main factors in scientific furnace design.

The efficiency of heating in the furnace itself is governed to a large extent by the rate at which the articles being heated can absorb heat. This again is effected by (a) Correct circulation of the gases over the material being heated; (b) the difference between the temperature of the gases and the material, and (c) radiation from the hot brickwork of the furnace walls.

The heat absorbed by the material depends on the material itself and the temperature desired.

The curve in Fig. 4 gives the heat content of pure iron and some of the more important non-ferrous metals at various temperatures, and is based on investigations by Wust.

The following example will make the use of this curve clear. Assume an iron billet weighing 200 lbs. is to be heated to a forging temperature of 2,400° F., and that the initial temperature of the billet when put into the furnace is 60° F. The heat content (above 0° F.) when the billet is charged into the furnace is 6 B.Th.U. per lb., and when uniformly heated to 2,400° F. is 375 B.Th.U. per lb. Therefore, $200 \times (375-6) = 73{,}800$ B.Th.U., the heat absorbed by the billet.

The correct circulation of the hot gases over the material being heated is governed by the location of the burners and flue openings in the furnace. The correct positioning of these is of vital importance and should be given every consideration if uniformity of temperature and efficiency of heating is desired.

The difference in temperature between the products of combustion and the material being heated depends of course upon the flame temperature developed. In the combustion of town's gas excess gas and also excess air in the air-gas mixture affects the possible flame temperature, and it is essential that if the maximum temperature is to be attained, combustion should take place without excess of either gas or air. The quantity of heat which can be given up by the products of combustion depends on the quantity of the gases, their mean specific heat and the difference in temperature between the flame gases and the flue gases. The maximum possible efficiency of heat transmission in a furnace chamber cannot exceed the fraction, $\frac{\text{theoretical flame gas temperature—flue gas temperature.}}{\text{theoretical flame gas temperature.}}$ Any increase in this efficiency must be obtained by either increasing the flame temperature or reducing the temperature of the flue gases.

The temperature of the furnace chamber governs the flue temperature and little can be done to reduce this, apart from correct arrangement of burners and flues, to promote good circulation of the products of combustion.

Increase in flame temperature can be obtained in two ways:—(1) By combusting only perfect mixtures of gas and air; (2) by recuperation or regeneration.

The heat lost through the walls of a furnace may amount to a considerable percentage of that supplied to the furnace unless attention be given to wall construction.

In a typical furnace heat is transmitted by radiation and convection from the burning gases to the inner surface of the firebrick wall, conducted through the brickwork to the outer surface, and then lost into the atmosphere by radiation and convection.

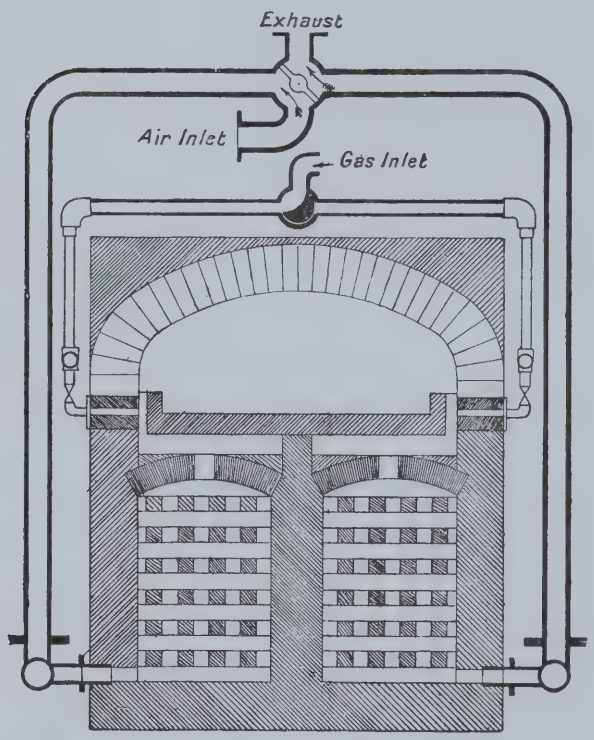

Fig. 9.

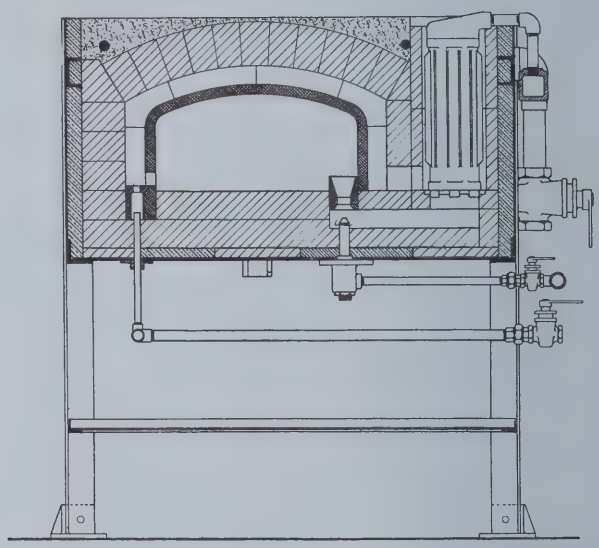

Fig. 10.

In general, in high temperature furnace construction there are two separate and distinct factors which must be given consideration if an effective wall is secured. A refractory material must first be provided capable of withstanding the working temperature and also having sufficient mechanical strength for the particular construction. The second factor is to prevent excessive loss of heat due to conduction through the walls. Rarely is a good refractory material a good insulator, and it is usually necessary to back up the refractory lining with some material having a much lower heat-conducting capacity. Many efficient insulating materials are available, and Fig. 5 illustrates the advantage of insulation in furnace walls.

The heat carried away by the waste gases depends on the quantity of the gases and their temperature, and can be reduced by careful regulation of the relative quantities of gas and air to ensure complete combustion without excess of either, and by ensuring that the wall construction is such as to reduce heat losses to a minimum. Thus by increasing the efficiency of the furnace the gas consumption required for the particular duty is reduced to a minimum.

The heat carried up the flue by the waste gases from a non-recuperative or a non-regenerative furnace is unavoidable, but attention to the points mentioned will reduce this loss to a minimum.

The effect of excess air in the air-gas mixture supplied to the burners is shown in Table III.

TABLE III.—PER CENT. HEAT LOSS.

Furnace Temp.	Excess Air. Per cent. CO_2.	20% 13.2	50% 10.5	75% 9.0	100% 8.0
3,000° F.	.. ..	11.5	29.0	43.5	58.0
2,000° F.	.. ..	7.0	17.5	26.5	35.0
1,000° F.	.. ..	3.0	7.5	11.3	15.0

The theoretical CO_2 content, when combusting a perfect mixture of gas and air should have been 16 per cent. Burner mixtures containing excess air cannot react as rapidly as perfect mixtures, neither can such mixtures react within a space as small as will suffice for a perfect mixture. The effect of excess air on the gas consumption of a furnace is shown in Table IV., based on tests conducted to prove this point. The table gives the gas consumption required to hold a given temperature, with varying percentages of excess air in the mixture.

Per cent. Air.	Temperature °F. 2,500°	2,200°	2,000°	1,850°	1,460°
0	165	120	95	70	45
20	200	127	100	74	48
40	300	150	107	77	53
60	700	245	120	90	57
80	not attained	355	145	107	63

Summarising the main factors requiring consideration in the scientific design of furnaces it is found that the following points should be given careful thought. (1) Air-gas proportioning; (2) air-gas mixing; (3) freedom from lighting back in the burner; (4) transmission of maximum amount of heat by radiation; (5) no flame contact with the material being heated; (6) efficient insulation of furnace walls; (7) choice of suitable refractories; (8) reduction of heat losses in waste gases.

Some examples of modern furnace design, incorporating the above factors, will now be described and illustrated.

The first type to be dealt with will be that known as the "surface combustion" furnace.

These furnaces are equipped with an automatic proportioning, one-valve control system, and two systems are available. The first, known as the low pressure system, uses gas at ordinary town's distribution pressure, together with air under a pressure of $\frac{1}{2}$lb. per sq. in. or upwards. The second, or high pressure system, uses gas under a pressure of 2 lbs. to 10 lbs. per sq. in., and the total amount of air for perfect combustion is inspirated from the atmosphere. Either of these air-gas proportioning systems makes it possible, by simple one-valve manipulation to vary over a wide range the quantity of gas consumed by the burners, without in any way altering the predetermined proportions of the gas and air in the mixture supplied to the burner. Both systems ensure that efficient mixing of the air and gas takes place after the correct proportions have been obtained, and the mixture, on reaching the burner nozzle, is in a thoroughly homogeneous condition.

Two types of burner are generally used and are known as the Refractory bed type and the Tunnel type. Both bring about the desired intense temperature, but each has distinct characteristics in its action of distributing the heat in the furnace. Intense temperature is obtained in both cases by localising the zone of combustion, in the first case, by impinging the mixture upon a bed of refractory granules, and, in the second, by sudden expansion in a moulded tunnel. The intensely hot surface of the granules, or the tunnels, has a considerable accelerating effect on the speed of combustion, so that these two conditions, both increasing each other, gradually build up an intense localisation of the combustion.

In the Refractory bed type of firing, Fig. 6, the burner projects the homogeneous mixture of gas and air into a pocketed bed of refractory granules at a sufficient velocity to carry the mixture into the bed prior to combustion. The zone of combustion forms at the point within the bed at which the flow speed equals the rate of flame propagation. As the velocity of the issuing air-gas mixture is maintained above that of the propagation of flame, danger of lighting back is eliminated.

Combustion occurs in the interstices of the refractory raising the entire mass to incandescence. With the proper use of refractory material in porous, granular form, it is possible to form sources of radiation which are capable of far greater intensity than that of any flame.

With the Tunnel type burner, Fig. 7, an accurately moulded, minimum size, combustion chamber is formed in the furnace wall and lined with highly refractory cement. The combustion chamber, or tunnel, is of the smallest space in which the mixture capacity of the particular burner could be burned. In other words, after temperature is attained it can be considered that the gases issuing from the tunnel are burned gases at a temperature very closely approaching the theoretical flame temperature.

The heat distribution obtained with the tunnel type burner within the furnace, is a function of the velocity of the issuing gases, for although radiant heat is obtained from the furnace walls, this is primarily produced by transfer by convection from the gases.

From the description given it will be seen that the conditions are perfect for the production of high flame temperatures, maximum amount of heat in radiant form, and minimum volume of products of combustion. With either type of burner combustion may be considered as flameless. A cross section of the surface combustion furnace is shown in Fig. 8.

The regenerative type of gas-fired furnace is well illustrated by the furnace illustrated in Fig. 9. The principle involved is a system of furnace firing, whereby a larger proportion of the heat usually escaping through the flues of the furnace is regenerated and made to serve in the operation upon which the furnace is engaged, than is the case in the usual type of gas-fired furnace.

Hitherto, the heat losses, by way of the flues of the furnace, have been excessive, amounting in the case of a furnace working at 1,000° C. to as much as 45.5 per cent. of the total heat generated by the combustion of the gas, but in the furnace illustrated these losses are reduced to a minimum, as is clearly shown by the fact that with a furnace working at 1,050° C. the flue gas temperature has been as low as 65° C. —this being brought about by the system of regeneration adopted.

Probably the best example of recuperative type of gas-fired furnace is the " Roberts-Booth " patent furnace, and a forging furnace designed on this principle is illustrated in Fig. 10, and is arranged for a working temperature of 1,400° C. The burners are arranged to fire in a vertical direction at the right hand side of the hearth, and the products of combustion sweep across the heating chamber from right to left.

On the left hand side on the level of the hearth exit ports are arranged through which the hot gases pass. After passing through these ports the gases again encircle the combustion chamber behind a form of muffle. The gases then reach the recuperator which is of the metallic tube type. The air for combustion passes down the inside of the tubes, whilst the hot gases ascend around the outside of the tubes. With this system of recuperation the process is continuous and no change-over gear is necessary. The recuperator is compact and no excavations are necessary for large chequer brick chambers. Careful tests have shown that this form of recuperator will extract 70 per cent. of the heat from the waste gases, this heat being returned to the heating chamber in the air for combustion. In forging operations it is necessary in order to reduce scaling or oxidation to a minimum, to maintain a reducing atmosphere in the furnace chamber, and the maintenance of such an atmosphere is carried out by suppressing the main air, and in other words having unconsumed fuel in the chamber.

In the design of furnace referred to, the unconsumed fuel is burned by the admission of secondary air immediately after the gases leave the combustion chamber and before reaching the recuperator. This method ensures that even with incomplete combustion in the furnace chamber this is not attended by a low fuel efficiency. The muffle construction of the furnace, due to which the flue gases surround the heating chamber, causes the heat loss, which must inevitably take place through the outer walls, to be taken from the flue gases instead of the heating gases.

A furnace of this type for a working temperature of 1,700° C. in the chamber showed a flue gas temperature of only 300° C. after 5 hours operation, while the outer wall temperature was 80° C. after the same period.

Chapter 5.

THE USE AND ECONOMIES OF DOMESTIC GAS.

By R. J. Rogers.

Although the enormous strides that have been taken in the use of gas for domestic heating in recent years lead many to think that its use in this direction is a comparatively recent development, one finds that its possibilities in this direction were recognised from the earliest days of its history.

To-day, gas is used so largely as a domestic fuel, that a consideration of its applications is essential if one is to obtain a true idea of the domestic fuel problems of Great Britain to-day.

Basis of sale—thermal values.

Gas is now generally sold upon a thermal basis. Each gas undertaking decides upon a definite calorific value below which its gas shall not fall. This is known as the " declared calorific value " for that particular undertaking. This value differs over a wide range and values have been declared as high as 640 British thermal units, and as low as 320 British thermal units. Many different factors influence the engineer in deciding upon what calorific value can be most economically declared. It depends on the type of retorts in use, the source of the coal usually purchased, the general local market for coke, the load on his distribution system, the incidence of demand throughout the day and its relation to storage capacity, while he has also to bear in mind any alterations or renewals in carbonising plant that may be necessary in the future.

An analysis of the declared values for Great Britain, shows a decided preference for the band of values lying between 450 and 500 B.Th.U.'s, and experience shows that all reputable makes of gas appliances are easily adjustable to give their maximum efficiency on any chosen point on this quality range.

Once the quality has been decided upon by an undertaking, it is very necessary that this should be kept uniform. Up-to-date methods of carbonisation permit the engineer to put out on his district, gas of a uniform calorific value throughout the year, no matter how much the demand for volume of gas may vary.

Pressure.

The correct consumption of gas in all types of atmospheric burners is dependent, not only upon uniformity of calorific value, but also upon a uniform and sufficient pressure. Domestic heating appliances are usually designed to burn " low-pressure " gas, that is, gas the pressure of which above atmospheric pressure is not usually more than six inches of water column. The specific gravity of gas being less (about one half) than that of air, pressures in mains tend to rise in the higher portions of a district. In hilly towns, therefore, it is usual to fix " district governors " at various points to ensure steady and unvarying pressures in all districts. The conveyance of gas at high pressures (say up to 10 lbs., per square inch), is being widely employed to cope with the distribution from large works to neighbouring villages or outlying suburbs.

Its use in this connection enables much smaller mains to be used, thus saving cost on the pipe-line and also reducing the cost of laying the main. Apart from cost, the congestion of pipes under the central streets of our large cities renders the laying of large diameter mains a matter of great difficulty. The reduction in capital outlay thus secured often allows a supply to be given to a village which is too far distant from the works to make the laying of a full-size low-pressure main a paying proposition. Once having reached the suburb or village, the gas is passed through a district governor, where the pressure is reduced to that required by normal low-pressure working. Any scattered houses passed on the way are each supplied with an individual governor on the service supply, and the gas metered in the ordinary way.

This method of distribution is gradually rendering available the supply of gaseous fuel to a still wider area, and its further extension will do much to render the villages less dependent on towns for smaller industrial heating operations, and will foster the growth of rural industries.

Use per consumer.

Very large variations in the average amount of gas consumed per meter are found as one goes from town to town. These are caused, partly by difference in the amount of service offered and publicity work done by individual undertakings, and also, very largely, by special local conditions. For instance, we find that in some mining districts many of the families receive a weekly allowance of coal, either free or at a nominal cost. On the other hand, in seaside resorts where there are a large number of boarding houses and hotels, the consumption per consumer is usually high. The use of gas as an industrial fuel is so extensive and varies so much in proportion to total consumption from town to town, according to the nature of the trades carried on there, that it is difficult to ascertain those areas where gas, as a purely domestic fuel, is most popular. The following list (extracted from Field's analysis, 1925) of consumptions per automatic (*i.e.*, 1d. or 1s. prepayment) meter, in different localities is however very interesting, as the average class of property in which such meters are fixed is fairly comparable in each city.

	Therms per consumer per annum.	Percentage of automatic consumers having stoves on hire.
London and suburbs	122.81	93
Bath	147.61	96
Bristol	142.08	105*
Birmingham	140.67	96
Leicester	131.14	97
Plymouth	125.17	88
Salford	70.07	79
Manchester	97.17	81
Oldham	60.14	—
Sheffield	55.86	10
Bradford	52.98	—

* This indicates that, on the average, more than one stove per consumer is in use.

From this it will be seen that there is apparently more gas per consumer burned in artisan dwellings in the Midlands and south than in the north. This is probably to some extent due to the fact that the more inclement weather in the north renders a fire in the kitchen necessary more continuously than in the south, and this fire is therefore used for cooking purposes, which is to some extent borne out by the percentage of automatic consumers who have stoves on hire.

As was proved in the general strike and the coal troubles which preceded and accompanied it, this universality of the gas cooking-stove did much to mitigate the sufferings which would otherwise have occurred among the poorer classes of our industrial towns. It is this class, which has no facilities for solid fuel storage, or if such exists have not sufficient reserve of money to buy coal in bulk, who are the first to feel the pinch in trouble either in the coal or transport industries. The prepayment meter, giving them a ready fuel payable on a day-to-day basis, has proved a great boon to them. It is probably not fully realised how great a part was played by the gas industry during the coal strike in 1926, and there is no doubt that, but for the successful efforts made by it to secure continuous supplies right through the trouble, conditions in many cities would have been critical.

Domestic gas and fuel economy.

It may be interesting to consider what effect the replacement of town's gas for raw coal as a domestic fuel would have upon our national coal resources. Any comparison of gas with raw coal, from this standpoint, must necessarily take into consideration the thermal efficiency of the gas work's carbonisation of coal, for whereas if raw coal be used, all losses take place actually at the point of combustion in the domestic grate, when town's gas is used the thermal losses take place in two stages, firstly in carbonisation, secondly in utilisation.

It is estimated that, on the average, every 100 units of heat delivered to the gas works in the form of coal is split up in carbonisation as under:—

Heat content in gas sold	22.9
„ „ „ „ lost	1.6
„ „ „ coke sold	46.25
„ „ „ tar sold	5.8
	76.55
Heat used and lost in manufacture	23.45
	100.00

If, therefore, we debit the gas delivered to the consumer with the total losses in manufacture and distribution, we find that, treated solely as a gas-producing operation, the thermal efficiency of carbonisation plus distribution to the consumer is 47.8 per cent.

Total heat lost in manufacture	=23.45%
„ „ gas made	=24.5 %
	47.95%
Total heat in gas delivered to consumer	=22.9 %

Therefore, for gas percentage thermal efficiency of carbonisation plus distribution to the consumer is:

$$\frac{22.9}{47.95} \times \frac{100}{1} = 47.8\%$$

This efficiency must be combined with the thermal efficiency of the various domestic gas appliances before we can give a utilisation efficiency as compared with raw coal.

The thermal efficiency of the gas fire may be taken as 70 per cent.; geyser as 80 per cent.; and the gas ring as 50 per cent., and so the thermal efficiency of these apparatus in relation to fuel consumed in manufacture may be taken as :—

Gas fires 70% of 47.8 = 33.4%
Gas geysers 80% of 47.8 = 38.24%
Gas rings and Gas wash coppers } 50% of 47.8 = 23.9%

The efficiency of the oven has been purposely omitted, for whereas it is easy to get a comparative test between ovens based on utilisation, it is very difficult to get any scientific test that will give actual thermal efficiency.

The above efficiencies are therefore directly comparable on a raw fuel consumption basis with the efficiency of the kitchen range or room grate. These may be taken as:—

Modern coal fire for room warming (Fishenden), 30 per cent.; back boiler for bath water, etc. (Barker), 11 to 12 per cent.; saucepans or kettles on range (Barker), 1 to 5 per cent efficiency.

The figure of 30 per cent. for a coal fire is, of course, for long period use. If it were needed for short periods its practical efficiency would be much lower.

It will therefore be seen how great would be the saving in coal to the nation if gas heating were substituted for raw coal in domestic heating processes, quite apart from the fact that the carbonisation of coal makes available a very serviceable smokeless fuel—gas coke—and also results in the production of many valuable by-products—fertilisers, dyes and other chemicals.

Gas and modern housing problems.

Two or three causes have conspired together to change entirely the housing outlook in this country. The suspension of building during the war and the great rise in the cost of building materials and labour since, have caused an abnormal shortage of houses. The improvement in education and also in the general standard of living, have created a demand for houses more scientifically planned to save labour and to admit light and air. Unfortunately, the high cost of materials has prevented the fullest use being made

of our improved knowledge in everything relating to domestic architecture. By the adoption of gas for heating, however, the opportunity is afforded for securing reduction of building cost. Experience shows that massive and expensive chimney breasts are unnecessary with gas fires, and that perfectly efficient ventilation may be obtained from a 9 by $4\frac{1}{2}$-in. flue so long as this is taken above the ridge of the roof. Fig. 1 shows how such flues may be incorporated in a brick-built wall. They may also be built up of special concrete flue blocks arranged to bond into the ordinary brick courses.

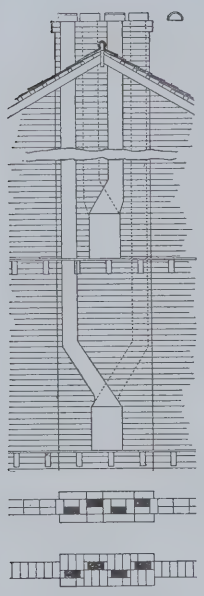

Fig. 1.

The use of gaseous fuel through prepayment meters has done much to improve the standard of living in poor and crowded areas of our industrial centres. Far better results can be obtained from the gas cooker than from the small inefficient kitcheners usually found in this property. Throughout the summer the tenants have not to endure the heat of a fire in their small, and often overcrowded living room. The house is easier to keep clean and a more varied dietary can be prepared, while the tenants do not suffer from artificial inflation in the price of their fuel during the winter months when their circumstances are often most straitened.

The main purposes for which fuel is required in the average house are of course cooking, room warming, and the provision of hot water, together with such subsidiary needs as ironing, airing clothes, etc.

From time to time various alterations and improvements are made in the construction of gas cookers. These may be roughly divided into:—1, those affecting thermal efficiency; 2, those affecting convenience in use; 3, those affecting hygiene.

Considerable improvement has been made in the design of the hot-plate burners during the past few years, and special care has been taken to ensure, in the latest patterns of cooking stoves, that no carbon monoxide is present in the products of combustion.

Where drilled burners are used, attention is given to such drilling, in order that it shall be at the angle which gives the greatest efficiency in general use. As an alternative to these burners, we have the "solid flame" type which enables the ring to be brought very close to the vessel to be heated and secures excellent flame contact, at the same time ensuring complete combustion.

In the old type of hot-plate, heat losses occurred owing to the positioning of the burners too close to the cornice, which was itself often of too heavy a pattern. Losses also occurred due to the heating up of the top bars. These are now made in open patterns, so that there is no contact between them and the flames. As a result of investigations carried out by the National Gas Council, it has been laid down that where drilled burners are used there should be a definite distance of $1\frac{1}{4}$in. between the top of the burner and the bottom of the kettle or saucepan which is to be heated. The closed-in or "smooth top" hot-plate has its advocates and is certainly convenient in use. It is particularly suitable in large kitchens and restaurants, where the hot-plate is kept at maximum output over long periods, and its use is likely to be extended in the near future.

Fuel cost.

Although it is difficult to give a definite thermal efficiency to an oven it is very simple to find the actual practical efficiency of the boiling burners on the hot-plate. Experiments show that, under ordinary conditions, using ordinary aluminium kettles and saucepans, 50 per cent. or a little more of the heat of the gas is transferred to the water. To boil a quart of water would therefore require about 800 British thermal units, which at 8d. a therm will cost .064 of a penny, or about $\frac{1}{4}$d. per gallon.

Considerable research has been carried out as to the ventilation of the gas oven. There are upon the market cookers, the ovens of which are heated externally, but these do not meet with approval in all cases.

The internally-heated oven is by far the more common, and the efforts of manufacturing research have been in the direction of regulating the throughput of air in the oven, and also of controlling the temperature thermostatically. The two most common methods of regulating the secondary air are by

placing the flue outlet near the bottom of the oven, or by placing it at the side, with a partially closing butterfly valve in the outlet which is connected with the oven gas-tap, which reduces the area of the flue outlet as the gas is lowered, though always leaving a margin of safety to prevent the possibility of the flames being smothered. It should be noted that with the flue near the bottom and thermostatic control, the whole of the oven space is approximately at one temperature.

The question of the ventilation of the cooker is one to which prominence has been given in recent years. This is due very largely to the construction of small sculleries without chimney ventilation. It is not sufficient to fix a flue to the oven only, as in the majority of cases 60 to 70 per cent. of the gas consumed is used on the hot-plate burners. In any case it is undesirable to fit any considerable length of flue pipe to the oven outlet as this increases the flow of secondary air through it and tends to decrease its thermal efficiency. It must be borne in mind that in no case must a flue run direct from the oven outlet to the open air, as there is always a possibility of a puff of " down draught " extinguishing the gas at the burners.

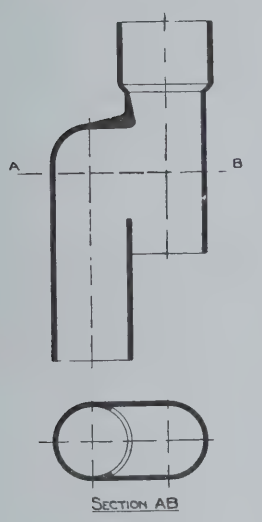

FIG. 2.

A simple but effective fitting (Fig. 2) is now on the market which provides a break in the flue which not only prevents any excessive pull where a long length of flue pipe has to be used, but also provides an open end for down draught and so prevents the gas at the burner from being blown out.

Room warming.

In the design of the modern gas fire manufacturers have carefully kept the question of air change before them, and the area of flue outlet from the fire to chimney has been arranged accordingly. Buyers may rest assured that a gas fire of any reputable make, if fixed correctly to a chimney, will not only remove from the room its own products of combustion but will also ensure a normal air change in the room (Fig. 3).

Prior to the full realisation of the vital necessity for air change, the feeling of stuffiness experienced in some rooms where old-fashioned gas fires were employed was attributed entirely to the fact that from such fires convected heat was given off. Makers, therefore, in addition to greatly increasing the flue outlets and improving canopy designs, concentrated upon securing the maximum of radiant efficiency and cutting out entirely any heating by means of convection. There is a growing feeling however that so long as adequate ventilation is assured, a certain amount of low-temperature convection is desirable to supplement the heat given off direct from the radiants.

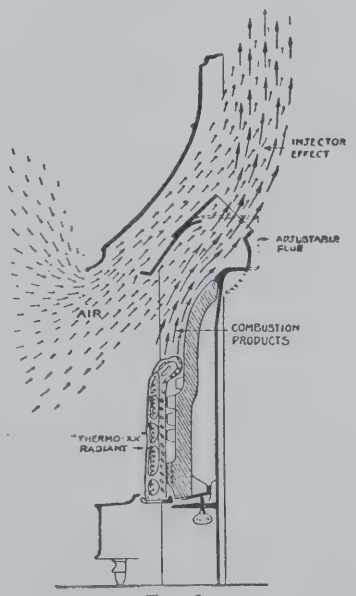

FIG. 3.

Several methods have been devised to obtain this proportion of convected heat without raising the temperature of the air too high at any point. One method is demonstrated in Fig. 4.

In this fire, cold air is drawn in near floor level and passes up a narrow chamber at the back of the fire and is given out as warmed air again at the top of the fire. The air, in passing through this chamber, is carefully sealed off from any possibility of admixture with the products of combustion. This type of fire has the effect of making the air of the room comfortably warm sooner than one which relies for its heating entirely upon radiation. A similar effect can be obtained from the arrangement shown in Fig. 5, which is designed for use in offices or rooms in which no chimney exists. Here, the metal box at the back of the fire becomes heated and convection currents are set up.

As the breathed air in a living room tends to rise owing to its decreased density, it is obvious that if it were possible it would be better to provide some outlet for it near the ceiling level. A fitting has recently been put on the market in the form of an injector ventilating flue block, which provides an inlet to the chimney from

the room just below ceiling level (Figs. 6 and 7). Tests show that a very considerable amount of vitiated air can be removed from a living room by this means.

Water heating.

The past few years have brought a vast expansion of the domestic heating load dealt with by the gas industry. It is probable that it is the water-heating section of this load which will show the greatest further increase in the near future. At the moment only a very small proportion of this field has been covered. All will admit that in very many houses in Great Britain the means taken for the provision of hot water are unsatisfactory. An improved knowledge of hygiene has shown us how essential personal cleanliness is to health, but in the greater proportion of houses no method of heating water exists independent of the kitchen range, yet any system of heating for domestic hot water must be independent if it is to be satisfactory. With gaseous fuel there are two main methods of securing a hot-water supply, namely, a geyser or instantaneous heater, or a circulator or boiler fitted with storage tank. The geyser is an extremely economical apparatus, its thermal efficiency being very high—over 80 per cent.—and its action rapid, but it requires a large consumption of gas for the short time it is in action. Two things are absolutely essential if the geyser is to work efficiently:—Adequate-sized gas meter and supply-pipe; the proper carrying away of the products of combustion at all times.

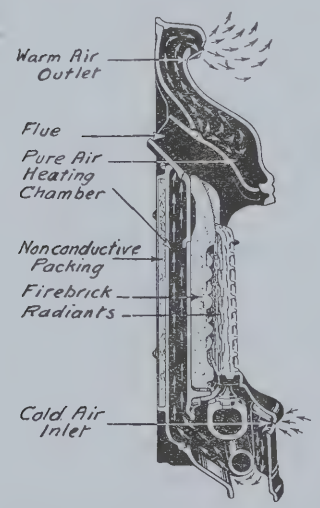

Fig. 4.

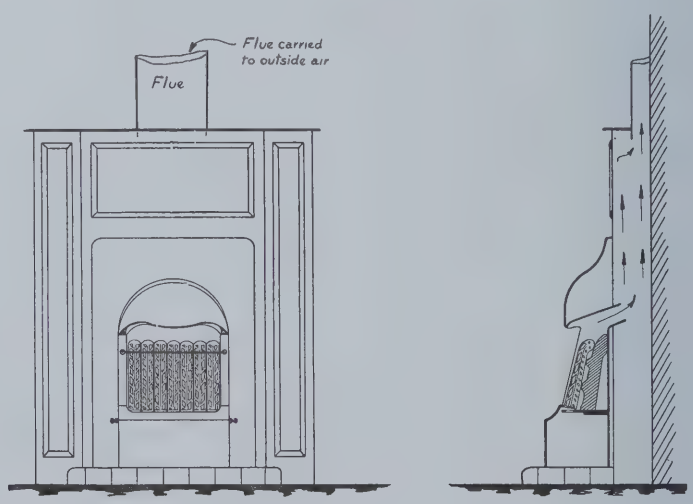

Fig. 5.

The first of these conditions is easily fulfilled, always remembering that it is preferable where possible that a gas supply-pipe be run direct from the meter to the geyser and that this should not in ordinary cases be less than $\frac{3}{4}$in. in internal diameter.

The geyser in the bathroom, of course, gives hot water only in the one room, but if an instantaneous heater of the " Califont " type is used, this may be arranged to give water over the sink as well, and at any other point in the house as desired.

The second method is to use a gas-heated boiler connected by flow and return pipes to a hot-water storage tank. This method gives wider choice of position for fixing the apparatus, and therefore it is easy to arrange for the flue from the appliance to be run into an adjacent permanent chimney.

The success of this system is very largely dependent on the way in which the water supply-pipes are run, and on the efforts made to reduce radiation losses from piping and cylinder. The gas is thermostatically controlled so that once heated up, if no water is drawn off, the gas consumption is cut down to an amount just sufficient to make good radiation losses.

The choice of boiler or geyser is greatly influenced by the degree of hardness of the water which is to be dealt with. If the water is " temporarily " hard, then all narrow passages or small tubes must be

avoided or they will become clogged with lime deposit. If on the other hand the water is " soft," it must be remembered that such water has a corrosive effect on iron, even if the iron be galvanised. In this case both pipes and hot-water cylinder must be of copper, and the boiler either of copper or " bower-barffed " cast iron.

Of all the water-heating appliances in general use, it is probable that the back boiler of the ordinary range is the most inefficient. It is somewhat difficult to give definite figures, but it may be taken that it is unusual to get more than 11 to 12 per cent. of the heat in the coal transferred into the water.

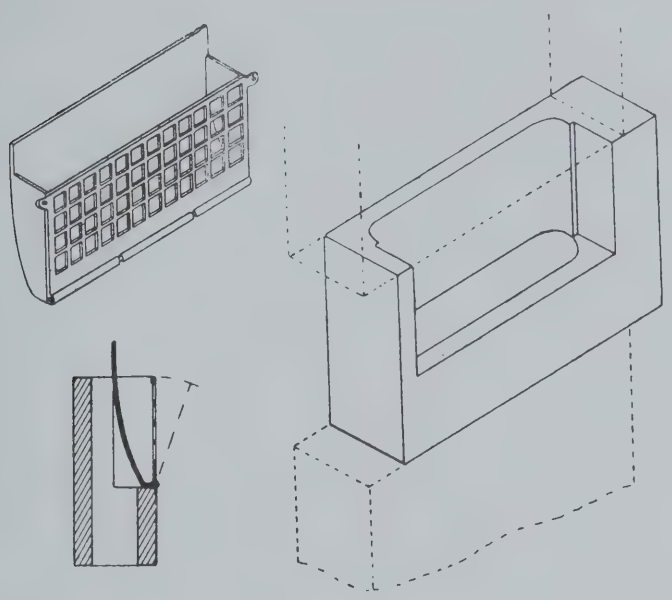

FIG. 6.

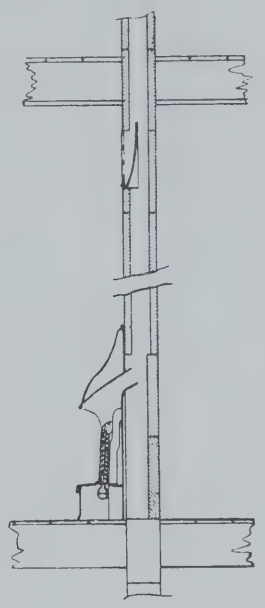

FIG. 7.

In this connection it may be stated than an efficiency of 30 per cent. and upwards is easily obtained from the small independent coke boilers for water heating now on the market, and judged solely on a fuel basis they represent the cheapest method of heating domestic water available.

The position which town's gas occupies in Great Britain's domestic fuel problem is best gauged by a consideration of the fact that, of the 170,600,000 tons of coal sold in the United Kingdom for home consumption during 1925, it is estimated that approximately forty million tons were burnt in domestic grates. The gas industry carbonises some eighteen to twenty million tons per annum, and there can be little doubt that if these figures were reversed by the increased use of gas for domestic heating, great saving in fuel would result, and the country generally would benefit by the lessened amount of smoke in urban districts, and the improvement in the cleanliness and comfort of our homes.

GAS WORKS COKE.

Chapter 1.

COKE PRODUCTION IN THE GAS INDUSTRY.

By H. Hollings, M.Sc.

When coal is carbonised in ordinary gas works retorts, without admission of steam, the residual coke is finally heated to a temperature of about 1,050° C., and the yield of dry coke and breeze is very slightly in excess of what would be indicated by a proximate analysis of the coal. Slight variations in the final temperature, and in the rate of heating may affect the quality of the coke, and still more the quality of the volatile products, but do not influence seriously the gross yield of coke and breeze. The coals generally used for gas making contain from 27 to 34 per cent. of volatile matter.

The admission of a controlled quantity of steam to the retort during carbonisation, which is a common practice with continuously operated vertical retorts, reduces the yield of coke owing to the formation of water gas, to the extent of from 3 to 7 per cent. of the weight of the coal, depending upon the proportion of steam actually decomposed. About half the coal used in gas works in Great Britain to-day is carbonised in vertical retorts, and some steam is admitted to most of these.

A proportion of the coke and breeze resulting from the carbonisation of the coal is used in gas producers for the generation of heating gases for the retort settings. It is a common practice, in connection with horizontal retort settings, to discharge hot coke direct from certain retorts into the producers built as a part of the setting. In other cases cold coke is used in external producers. The coke so used is seldom weighed directly, but it may be taken as equivalent to from 2.5 to 3.5 cwts. of dry coke, per ton of coal, the average being under 3 cwts. in modern settings. In addition, some breeze is used for steam raising in connection with the power requirements of machinery used for handling the coal and its products. During recent years, however, the installation of boilers heated by the waste gases leaving the retort settings, has reduced considerably this consumption of fuel. There are in fact plants which derive all steam required for purely gas making power purposes and for admission to the retorts from waste heat boilers and have, in addition, a small surplus of steam available for other purposes.

The following table shows the quantities of gas coke and breeze made, and also the quantities used for water gas manufacture, sold in Great Britain, and exported during recent years. The quantities given as used for water gas manufacture refer to statutory undertakings only.

	1922 Tons.	1923 Tons.	1924 Tons.	1925 Tons.
Coal used	16,556,134	17,202,476	18,104,400	17,798,725
Gas coke and breeze made ...	10,862,666	11,508,241	12,085,691	11,832,842
Gas coke and breeze used for water gas manufacture ...	1,057,909	906,717	976,366	1,153,413
Gas coke and breeze sold in Great Britain	7,737,718	7,542,867	7,419,305	7,396,681
Gas coke and breeze exported ...	911,307	1,224,302	964,539	889,281

Thus it may be stated that the gas works of Great Britain carbonise 18 million tons of coal per annum, and produce 12 million tons of coke and breeze, of which $2\frac{1}{2}$ million tons are used in connection with the carbonisation process, 1 million tons are used for making water gas, which is mixed with the coal gas, 1 million tons are exported, and $7\frac{1}{2}$ million tons are sold in the home markets.

The mixture of coke and breeze as it leaves the retorts is quenched, if necessary, and is then screened so as to grade it into sizes suitable for different purposes. That which is above 2 inches in size is sold as large coke, a smaller grade is that which passes through a 2-inch mesh and over a $\frac{3}{4}$-inch mesh. It is usual, however, to adopt a much closer grading of coke for use in domestic and other small appliances ; for example, there is a great demand for coke nuts passing through a $1\frac{1}{4}$-inch mesh and over a $\frac{3}{4}$-inch mesh. For use in forges smaller nuts from $\frac{3}{8}$ inch to $\frac{3}{4}$ inch are prepared. Except when this small forge coke is separated, all that passes through a $\frac{3}{4}$-inch mesh is sold as breeze. Generally, the amount of breeze produced per ton of coal, other than that used with larger coke in producers, amounts to from $\frac{3}{4}$ to $1\frac{1}{2}$ cwts. per ton of coal carbonised, but further quantities may be produced during the subsequent handling and storage of the coke. It is impossible to present any general statement regarding the relative quantities of the several sizes of coke made, as they are governed not only by local demands for particular grades, but also by factors peculiar to each gas works plant.

Gas coke is used very generally for heating systems in public and private buildings and in greenhouses, and finds application in industries so diverse as the baking of bread and the casting of iron and also in the raising of steam. The breeze is particularly suitable for use in chain grate furnaces. Whatever the purpose for which gas coke may be used, close attention should be paid to the grading and to the relationship between the size of the furnace and the size of the coke. Uniform and easy combustion, with the minimum formation of clinker, depends in no small measure upon proper attention to these factors, especially in the case of small furnaces such as are found in domestic appliances.

Definition of properties.

In order to define the properties of any sample of gas coke and estimate its suitability for any particular use, it is necessary to consider the following characteristics :—(1) Its size and the degree of uniformity of size; (2) Its mechanical strength; (3) Its weight per unit volume; (4) Its ash content, and the nature of the ash; (5) Its moisture content; (6) The volatile matter remaining in the coke; and (7) The chemical behaviour of the coke towards air, steam, and carbon dioxide.

The significance of each of these characteristics is explained elsewhere in this volume.* At this stage, it is proposed to consider the several factors which govern them.

The coking properties of the coal or of the blend of coals used, are obviously of primary importance in determining the quality of coke produced ; these are discussed in greater detail in another chapter,† but it may be mentioned that they often determine what type of carbonising plant is best suited for particular coals. For example, the coal which shows little tendency to swell during carbonisation may be carbonised at a high rate in continuously operated retorts, but if it also possesses feeble caking properties it will give a mechanically weaker coke than it would in certain intermittent systems. Coals with a marked tendency to swell during carbonisation are most easily treated in horizontal retorts, but within recent years the temperature conditions in continuously operated vertical retorts have been so adjusted that it is quite practicable to carbonise in them ordinary Durham gas coals. Adjustment of caking properties by the blending of two or more coals is a development which is also receiving considerable attention within the industry at the present time.

It is also to be noted that in some instances coal is screened prior to carbonisation so that the finer coal may be carbonised in horizontal retorts, the throughput of which is dependent upon the size of coal to a less degree than is that of a continuously operated plant. It is known that when certain gas coals are screened in this way the coking properties of the two fractions are different as also are the ash contents and other characteristics, but the real significance of these differences remains to be determined.

The strongest coke mechanically is often the most dense ; some of the densest cokes, which may be made from finely crushed blends of coal, however, have a tendency to split into small pieces which is not always desirable.

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*Metallurgical Coke, Chapter 1.
†Gas Works Coke, Chapter 2.

In horizontal retort practice it is found that any increase in the depth of the charge of coal, whether it results from a better filling of the retort or from the adoption of a larger section of retort, results in the production of a coke of slightly greater density.

The size of the coke finally available for the market is also affected by the arrangements adopted for discharging it from the retorts, for handling, and for storing it. There is reason to believe that in existing forms of continuously operated vertical retorts the coke-extracting gear is responsible for some breakage of large coke. In all cases it is obvious that efforts should be made to cause the coke after it leaves the retort to slide over a surface rather than to fall through any appreciable height. In this connection it is found, also, that rubber belt conveyors are preferable to the push-plate conveyors which are not uncommon in horizontal retort houses.

Much of the breeze produced in gas works results from the necessity for stocking coke in large quantities at certain seasons of the year, and from the consequent double handling of the coke. For this reason the supply of breeze is somewhat irregular.

Ash content.

The ash content of coals used in gas works is generally higher than that of coals available for the coke-oven industry, and it should be remembered that the proportion of ash in the coke is determined almost entirely by the ash content of the coal. The ratio of " per cent. ash in coal " to " per cent. ash in coke" is equivalent to the gross yield of coke and breeze. The fusibility of the ash depends upon the nature of the original coal, but any tendency to form clinker is aggravated by the production of high temperatures locally. Such high temperatures may result from the employment of an excessive draught of air, necessitated by imperfect grading of the coke or from a compression of the whole zone of combustion, such as occurs when the chemical reactivity of the coke towards carbon dioxide is low. Thus the tendency of a coke to produce clinker may be estimated approximately, but not absolutely, from a determination of the melting point of the ash. When fusion of the ash does not take place, it is sometimes of some interest to note whether the ash exists in part as more or less coherent pieces of shale, or whether it is disseminated throughout the mass so as to produce a fine powder. This of course depends upon the nature of the coal and the degree to which it has been crushed prior to carbonisation.

Increased attention is being paid to the moisture content of coke, and in this respect the continuously operated plant has a distinct advantage over the intermittent plant, for when steam is admitted to the coke chamber at the base of the retort a perfectly dry but quenched coke may be discharged. The production of dry coke from horizontal retort systems without the risk of coke fires in storage hoppers, is dependent upon efficient supervision of water sprays. Various systems for dry quenching coke from horizontal retorts have been proposed but have not been adopted to any extent.

The proportion of combustible volatile matter remaining in gas coke is usually slightly higher in gas coke than in coke-oven coke, owing to the shorter time of carbonisation. It depends upon the final temperature attained by the coal within the retort, and to some extent upon the nature of the coal. The uniformity of distribution of the volatile matter is of some importance as affecting the strength of the coke and its behaviour during combustion, and this is of course governed by the design of the carbonising plant and the conductivity of the coal-coke mass during carbonisation. For example, the volatile matter is more uniformly distributed in a coke resulting from carefully blended coals than in one from a coal which passes through a highly plastic stage during carbonisation. For the purposes for which gas coke is usually employed the presence of up to about 2 per cent. of volatile matter is advantageous ; any higher proportion is usually indicative of the presence of imperfectly carbonised coke in the centre of the charge, and of mechanical weakness of some of the pieces of coke.

The chemical behaviour of coke towards air, carbon dioxide, and steam presents problems of considerable interest, both from the scientific and from the practical point of view. This is still a matter for further investigation, so that a full discussion of it is outside the scope of this work. Attention has been directed to the subject within recent years by the observation that coke prepared from slightly swelling coals, or from blends of swelling and non-swelling coals, is in general more reactive than that prepared

from coal which swells and becomes plastic during carbonisation. This property appears to be associated with a more uniform and porous cellular structure of the coke. An increase in reactivity also results from the admixture of certain inorganic compounds, such as sodium carbonate with the coke, or with the coal prior to carbonisation.

Our knowledge of the correlation of the several reactivities towards air, carbon dioxide, and steam, and of the influence of temperature upon each of them is still far from complete. To illustrate the importance of further investigation of the matter, it may be mentioned that in the manufacture of water gas the reactivity of coke towards carbon dioxide is responsible for the loss which occurs in the form of carbon monoxide in the blow gases, but that on the other hand a high degree of reactivity towards steam during the gas making period, or run, is desirable for obvious reasons.

Again, the formation of flame above an open coke fire probably depends upon the formation of carbon monoxide as a result of reaction between incandescent coke and carbon dioxide, and the ease of ignition of coke probably depends upon the degree of reactivity towards air at some relatively low temperature.

Chapter 2.

BLENDING IN GASWORKS PRACTICE.

By John Roberts, D.I.C.

In the main, the principles involved in blending apply equally to gasworks practice and coke manufacture, but the problem entails certain considerations in the former industry which are not so important in the latter. Chief among these is the fact that the size of material best suited for making coke is not the most suitable for gas-making. In blending coking coals with inert material, it is advisable to crush the fuels fine enough to pass a $\frac{1}{4}$-inch sieve, 1/10-inch for preference, as efficient grinding is essential to successful blending. This tends to ensure the production of an even-textured coke, having the ash evenly distributed. In gasworks practice, on the other hand, a rapid gas yield is the chief desideratum, the quality of the coke being usually regarded, mistakenly perhaps, as of secondary importance, and finely-crushed coal does not make for rapid gas yields.

The behaviour of the plastic layer during carbonisation calls for equally as much study in gasworks practice as in other carbonising industries, since its control determines the rate of heat penetration and rapidity of coking. Except in cases where the gases are caused to travel inwards through the charge, as for example in the Hird system of carbonisation, the plastic layer forms an almost impervious wall, the continuity and thickness of which varies with the coals used. The relative impermeability of this layer prevents the charge of coal being heated by convection, so that carbonisation is effected chiefly by conduction and radiation. It has already been shown (Chap. 2, Metallurgical Coke), that the plastic layer can be eliminated by preheating or blending; its behaviour also depends on the sizes of coal undergoing carbonisation.

COAL SCREENING FOR GAS MAKING

The question of the size of coal to be used in gas manufacture has received special attention by several investigators, notably G. Weyman, A. Parker, and T. Carmichael. Weyman arrived at the conclusion that:—"The size of particle is most important as interfering with the formation and continuity of this plastic layer. The larger the size of particle the less continuous the plastic layer and the more rapid is the carbonisation." He found that by increasing the sizes of coal up to a point, the rate of gas evolution increased, and considered that the size of the interspaces in the mass was of greater importance than the total free space. (*Journ. Soc. Chem. Ind., Vol. XL., No. 24, pp.* 300 T.-308 T.) "With coal containing all sizes the rate depends very largely on the difference between the maximum and minimum size. The more irregular the mixture, the better the results. Relatively small amounts of dust affect the rate very adversely; more so when the coal possesses an even gradation in size. For any size the following classes of coal are arranged in ascending order of maximum rate of carbonisation, there being a gradual transition from class to class :—Coking coals, gas coals, cannels, anthracitic coals and non-coking coals."

The finer material offers resistance to the passage of gases and sets up back pressure in the retort. A more even pull can be maintained when larger sizes of coal are used. Further, the continuity of the plastic layer diminishes the transfer of heat by convection, whereas with larger sizes and interspaces, convection comes into play.

Parker and his colleagues have carried out research on this aspect of gas making. They used an experimental horizontal retort, and worked with coal of the following sizes: $1\frac{1}{4}$ to $\frac{3}{4}$in., $\frac{1}{2}$ to $\frac{1}{4}$in., and 10 to 30 mesh, and it was found here also that the larger sizes gave a more rapid yield than the 10-30 mesh coal.

These results have been confirmed on a work's scale by T. Carmichael, at the Portsmouth Gas Works, where it has been the practice for a few years to separate the fines from the nuts, and to carbonise the nuts in Woodall-Duckham vertical retorts, and the fines in horizontal retorts. The results obtained are very striking, improvement being effected in every direction. "The actual increase in the thermal output of the coal was 10 per cent., and of the plant 20 per cent., and less sticking of the charge was experienced. The production per ton of coal carbonised rose from about 62 therms with the unscreened coal to 69.1 with the screened coal, while in the horizontal house the total therms evolved from the smaller grade of fuel dropped only to 68.8 per ton as

compared with 70.2 from the unscreened variety. . . . . The output of one bed of vertical retorts rose from 860 to 1,032 therms per day."

From the foregoing it will be seen that considerable benefits result from the removal of the dust from gas coal which is to be carbonised in vertical retorts. It will be noted also that Carmichael stressed the fact that sticking troubles were avoided. Other gas engineers have found that these difficulties can be completely overcome in practice, by mixing non-swelling or non-coking coal with swelling coals, such as those of Durham, while Parker showed that by blending with coke breeze larger volumes of gas for the same weights of coal were obtained from coal/coke mixtures at all stages of carbonisation.

Although the use of nut coal interrupts the continuity of the plastic layer in the mass of the charge, it does not eliminate the plastic layer in each individual piece of coal, and until this is accomplished the maximum advantage is not obtained. In Parker's work it was found that, in the early stages of the various experiments, the yield of gas from the finer material was greater than from the nuts, but as carbonisation proceeded, the gas yield increased at a greater rate, up to a point, from the larger pieces than from the finer stuff. This phenomenon

Table I.

Cubic feet of Gas per 30 lbs. of Coal.					Yield during each 15-minute period.			
Size of Coal.		1½ to ¾in.	½ to ¼in.	10-30 mesh.	Size of Coal.	1½ to ¾ in.	½ to ¼in.	10-30 mesh
Time Hrs.	Mins.	Test 1	2	3		1	2	3
0	5	12.6	15.5	14.5	Period.			
0	10	24.3	27.5	24.7				
0	15	34.7	37.1	33.5	1	34.7	37.1	33.5
0	30	60.7	60.9	55.2	2	26.0	23.8	21.7
0	45	82.3	81.2	74.4	3	21.6	20.3	19.2
1	0	101.0	99.3	91.9	4	18.7	18.1	17.5
1	15	117.1	115.2	108.2	5	16.1	15.9	16.3
1	30	130.8	129.5	122.9	6	13.7	14.3	14.7
1	45	139.9	142.2	136.4	7	9.1	12.7	13.5
2	00	143.4	150.7	147.3	8	3.5	8.5	10.9
2	15	145.4	154.0	152.3	9	2.0	3.3	5.0
2	30	146.8	155.9	154.6	10	1.4	1.9	2.3

calls for explanation. Now it is well known that the smaller the particle of coal the more rapidly will it be completely raised to a given temperature, and coal may be ground to such fineness that carbonisation can be accomplished almost instantaneously, and no plastic layer will be formed in the particle. On the other hand, a piece of nut size must of necessity be carbonised gradually, and as coking progresses in it, a plastic zone is formed; hence, this plasticity of the large particle must impede carbonisation. The net result is that in the earlier stages more coal is completely carbonised when fines are used than when nut coal is employed.

The condition of affairs becomes reversed a little later as a result of the formation of a continuous plastic layer around the mass of fine coal, while in the case of the nuts the plastic layer is not anything like so complete, and the process of heat penetration is assisted by convection currents between the particles.

The coking time in Parker's experiments was 2½ hours, and from the results published in his paper (see Table I.) it may be calculated that at the end of 1½ hours the percentage of the total yield of gas evolved from the largest size of coal was 89.1, from the middle size, 83.6, and from the smallest size, 79.5. These figures are important when considered in connection with the proposal to manufacture a type of semi-coke under high-

temperature conditions, and especially in relation to the work done at the South Metropolitan Gas Works under the direction of E. V. Evans (*Cantor Lectures*, 1924), to which we shall presently refer.

In Fig. 1, are shown two graphs which represent the rate of evolution of gas in Parker's experiments. Curve 1 gives the rate for the nut coal of largest size, and Curve 2, that of the 10-30 mesh coal. These graphs clearly show that the process of gas making may be speeded up by removing the fines from the coal, and viewed strictly from the gas maker's standpoint screening would be desirable. On the other hand, taking the broader view, it is of the utmost importance that fine coal should be carbonised economically, and as rapidly as the nut coal. How can this be accomplished ? This is where blending comes to our aid, and we shall presently show that comparable gas-evolution curves have been obtained in blending experiments in horizontal gas retorts.

BLENDING AND BRIQUETTING.

Weyman's results were similar in many respects to those obtained by Parker and his colleagues, and on the question of blending the former pointed out that : " The behaviour of the coal depends on the plastic layer and the extent to which the addition of the one coal to the other will affect this factor. In a way the results are similar to those obtained by mixing different sizes, *a non-coking coal added to a coking coal being equivalent to increasing the average size.*" (The italics are mine.) The South Metropolitan results seem to bear out the conclusions arrived at by Weyman.

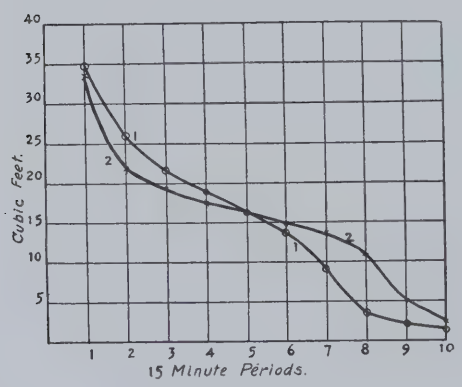


Fig. 1.

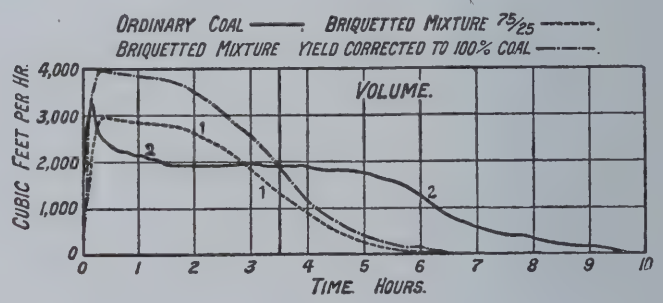


Fig. 2.

Reverting to Fig. 1, it will be noted that these two curves bear a striking similarity to the curves published by E. V. Evans in 1924, which are shown in Fig. 2. The latter graphs represent the rate of evolution of gas from a " straight " Durham coal and that from a briquetted mixture of the same coal and coke breeze, in the proportion 75 of coal to 25 of breeze. The form of the curve for the untreated coal, Curve 2, corresponds to that of the 10-30 mesh coal in Curve 2, Fig. 1, while the form of the briquetted blend, Curve 1 in Fig. 2, corresponds to Curve 1 of Fig. 1, from the nut coal. These graphs clearly indicate that where steps are taken to restrict the formation of the plastic layer, the rate of gas evolution is increased. This can be effected by removing fines from slack coal before coking, or by mixing inert fuel with the coking coal. In both cases also, sticking troubles are minimised.

The inert material may be coke dust, anthracite or non-coking coal of high volatile content. The latter fuel will generally be preferred for the reasons stated in the chapter on Preheating and Blending.

While it will in many cases be found to be a sound economic policy to adopt the plan of screening as at the Portsmouth and other gasworks, it follows also that it will, in several plants, pay to utilise fine coking coal mixed with non-coking coal, both of which grades are obtainable at less cost than ordinary gas nuts. The former system tends to the limitation of the selection of coals, while the latter plan enables gas engineers to draw supplies from a wider field, and at the same time encourages the recovery and production of coals not normally used for coking (which, for want of a suitable market are often left unmined), thus making for the conservation of fuel resources.

The advantages experienced at Portsmouth in carbonising screened nut coal in continuous vertical retorts had also been demonstrated in a somewhat different manner by the Research Section of the Woodall-Duckham Companies in a series of tests carried out in 1924 on similar retorts at a large gasworks, but in this case the fuel was first prepared as 3-ounce briquettes, in which there was a proportion of breeze. A pitch binder was used. Normally, rodding was necessary every two hours when running on ordinary gas coal, but it was found that briquettes were carbonised with far less trouble, the retorts running for 56 hours without showing any sign of sticking. Thirty-five tons of briquettes were carbonised in these tests, which showed that the throughput could be increased at least 40 per cent., when suitable briquettes were used. When mixtures of whole briquettes, broken briquettes and fines were used, the results were not so satisfactory, the throughput was reduced, and the retorts did not work quite so smoothly.

Thus it is clear that grading of the fuel for continuous vertical retorts is an advantage; if such grading provides also for the utilisation of the fine slacks, the maximum advantage is obtained. Where briquetting is resorted to, it is desirable that the proportion of pitch used should not exceed 5 per cent., or at the most, the amount of pitch yielded in the carbonisation process, so that the whole system is self-supporting in this respect. Usually, 3 per cent. of pitch is made in the process, and another 2 per cent. or so would be recovered from the pitch used as a binder.

The main advantages of briquetting for verticals and horizontals are: Increased throughput, higher yield of volatile therms, increased rate of gas evolution, greater ease of working, reduced capital charges and working costs, and economy of fuel generally. The briquettes should be non-swelling in order to derive the benefit of rapid heat penetration as a result of the elimination of the plastic layer. Here, it will be observed, that whereas the plastic layer is developed in individual nuts, it is not allowed, and cannot develop, in non-swelling briquettes; therefore, it is to be anticipated that where screened nut coal gives good results, briquettes should be doubly successful.

A further advantage of briquetting lies in the fact that, as E. V. Evans has shown, it is possible when working at high temperatures to arrest the process of carbonisation before completion, and leave about 5 per cent. of volatile matter equally distributed throughout each individual briquette. This is an important observation, and it points to a system of manufacturing smokeless semi-coke under high-temperature conditions. The same result can be obtained by blending without briquetting, and as the latter proposal led to the briquetting experiments referred to, it will be discussed rather fully.

THE MANUFACTURE OF SMOKELESS FUEL.

The question of manufacturing smokeless domestic fuel, or semi-coke, under high-temperature conditions, is a matter which interests both gas engineers and coke oven managers, and the arguments here put forward apply with equal force to coke oven and gasworks practice. Hitherto, the aim of the coke maker has been to produce a dense hard coke which would satisfy iron smelters, while the gas maker's object was to obtain the maximum yield of gas per ton of coal. Incidentally, the coke maker also, extracted practically the whole of the gas from the coal. I venture to suggest that in both cases the respective policies need modification.

In the first place, it is not absolutely essential to extract the whole of the gas from furnace coke, and in this assertion we have the support of H. Koppers and F. W. Sperr, both well-known authorities on coke manufacture, who have expressed the view that blast-furnace coke should be made at temperatures ranging between 650° and 800° C. (See *Stahl und Eisen*, 1922, Vol. 22, pp. 569-573, and *Blast Furnace and Steel Plant*, Aug., 1923, pp. 426-431.) Secondly, the function of coke ovens need not be restricted to furnace and foundry coke manufacture; there are great possibilities in their employment for the manufacture of semi-coke for the domestic market. Thirdly, the modification of policy suggested in the case of the gas maker, is that he should concentrate on making gas at the highest rate of efficiency, rather than endeavour to obtain the last trace of gas from the solid fuel. Incidentally, this will result in a desirable improvement in the coke produced at gasworks.

A smokeless domestic fuel to replace raw coal, should contain between 3 and 8 per cent. of volatile matter, dependent on the texture of the fuel. If the texture is such as to favour easy combustibility, a low percentage of volatile is permissible. Generally, however, at least 5 per cent. should be present. The fuel should be comparatively dense and of good crushing strength and hardness, so that it could be transported economically without

waste. The ash content should be below 8 per cent., and the moisture content below 2 per cent. A fuel having the foregoing properties should give satisfaction to consumers, and command a better price than " best house coal."

Although good gas coke and furnace coke, when properly graded, could with advantage be more extensively used than at present, the fact cannot be ignored that even when ordinary gas coke is placed on the

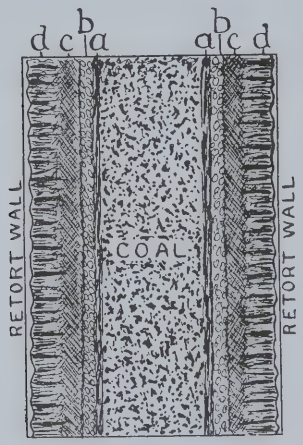


Fig. 3.

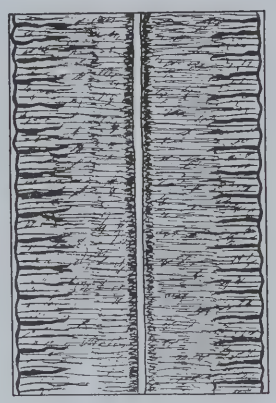


Fig. 4.

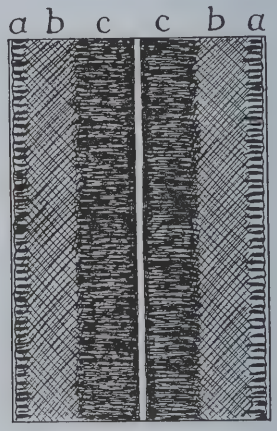


Fig. 5.

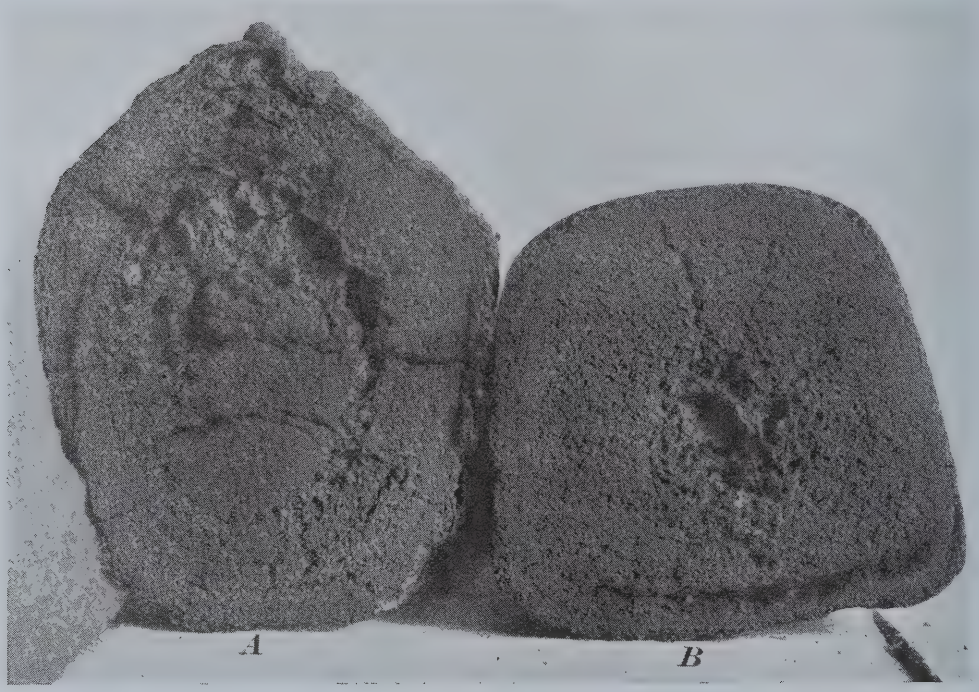


Fig. 6.

market at a considerably cheaper rate than house coal, householders still prefer smoky coal for open fires. This is due to the inherent shortcomings of gas coke, the chief being the absence of volatile matter. The complete extraction of the gas from the coal does not please the consumer, and an attempt will be made to show that it should be to the gas engineer's advantage to leave more gas in the coke. Similarly, the coke-oven manager may reduce

the cost of coke making, and increase the demand for his solid fuel, by manufacturing a fuel having the properties mentioned in the previous paragraph.

In order to explain the proposal, it is essential to touch briefly on the coking process, and to discuss the conditions prevailing in coke ovens and other static retorts when coal undergoes carbonisation.

When coal is coked in a coke oven of about 20in. in width, the flue temperatures employed may exceed 1,400° C., and the carbonising temperature reaches from 850° to 1,000° C. The rate of carbonisation is approximately 1in. in 1½ hours, so that the coking period is normally about 30 hours, which is a very slow process. The retort walls in a by-product oven being at a temperature of about 1,000° C., transmit their heat to the coal, which becomes coked from both sides. Owing to the low conductivity of coal, that nearest the walls becomes completely carbonised long before the moisture is driven off from the middle of the charge.

Fig. 3 illustrates the stages in the coking process, that represented being the state of affairs several hours after charging the oven, assuming that strongly-coking coal is being coked in a 20in. by-product oven. The middle portion is raw coal, the temperature of which may be as low as 120° C. even 16 hours after charging. The sections *a* represent the coal just when fusion takes place, this fusion zone being slightly ahead of the plastic layer *b*, which is very spongy. It is this plastic layer which resists the passage of heat through the charge. Next behind the plastic layer the zones *c* are semi-coke, adjoining which are the high-temperature coke zones *d*. The fact that the layers *b* impede heat penetration results in the concentration of the heat (from the oven walls) in *d*, which causes all the volatile matter from those layers to be expelled and the coke hardened, the typical cauliflower structure being developed near the retort walls.

At the end of the coking period the charge is completely carbonised to the centre, as illustrated in Fig. 4, and is then ready for discharging. If an attempt were made to push the charge, say 5 or 6 hours before the end of the normal coking period, it would be found that the middle of the charge would be still uncoked, while the major portion of it was thoroughly coked, and the charge would probably collapse and jam in the oven. Hence, the invariable practice is to continue coking until the middle section of the charge is in such a condition that the oven may be discharged successfully. Meanwhile almost all the volatile matter is driven off, and the bulk of the charge is hardened. The problem is, to carbonise to such an extent that the oven may be safely discharged while the average volatile content is between 3 and 8 per cent. To do this, it is essential to eliminate the plastic layer.

Referring again to Fig. 3, the drop in temperature between the coal and *d* is very steep, but the gradient can be reduced considerably if the plastic layer *b* is eliminated by blending strongly-coking coal with non-coking coal, or with coke dust, preferably non-coking coal. It has been demonstrated in several ways that when proper blends are used, the heat, instead of being concentrated in the outer layers of the charge, thus over-coking them, is transmitted with greater rapidity through the entire charge. It is only to be expected that the sides actually in contact with the walls will attain the wall temperature after a while, but the thickness of the hard coke layer will be very considerably reduced over that made with a " straight " coal under the same flue temperature conditions.

Fig. 5 represents the conditions likely to be produced when using a non-swelling blend of coking and non-coking coal carbonised under high-temperature conditions, the process being arrested when the temperature in the middle of the oven reaches about 600° C. The layers *a*, would be about 1½ to 2ins. thick, and would consist of fairly hard-baked coke. The portions *b* would be semi-coke, made at an average temperature of about 750° C., while the layers *c* would consist of black semi-coke, coked at an average temperature of about 650° C. The charge at this stage would be in a condition ready for discharging from the oven, and could be pushed without difficulty.

The photograph shown in Fig. 6 may be compared with the diagrams Figs. 3 and 5. This photograph clearly shows what takes place during the coking process. The specimen *A* is from a swelling coal, and *B* a blend of the same coal with 40 per cent. of breeze. The outer layers in *A* are completely coked, while the middle of the charge remained raw coal. Practically the whole of the charge *B* was carbonised in the same time under identical conditions, and gave a product having an average volatile content of nearly 7 per cent. These are the effects which can be reproduced on a large scale in horizontal and intermittent vertical gas retorts, and in coke ovens of the proper width, and having efficient heating arrangements. The point we would stress here is that the carbonisation of an optimum blend, whether loose or compressed, briquetted or unbriquetted,

is a totally different proposition from that of carbonising a normal coking coal, because the plastic layer exercises such a profound influence on the carbonisation process.

The advantages resulting from the elimination of the plastic layer are tenfold: (1) Swelling of coal is prevented and sticking troubles avoided; (2) Heat penetration is facilitated; (3) Coke of uniform texture is produced; (4) Coking period is reduced and retorts may be discharged at shorter intervals; (5) Throughputs of furnace coke or semi-coke are increased; (6) Rate of gas evolution is increased; (7) Fuel consumption per ton of coal carbonised is reduced; (8) Carbonising costs are cut down; (9) Fuels, otherwise non-coking, can be converted into coke, resulting in (10), the conservation of fuel.

It is advisable at this juncture to refer again to the South Metropolitan experiments. The rate of evolution of gaseous therms obtained by E. V. Evans with untreated coal and briquettes is given in the following table:—

Table II.—Rate of Evolution of Therms (Reduced to 100% Coal).

Charge.	1st hour.	2nd hour.	3rd hour.	4th hour.	4½ hour.	5th hour.	6th hour.
Untreated coal.	14	12	11.4	10.1		8.6	5.4
Briquettes.	16.4	13.34	7.94	3.33	1.5		

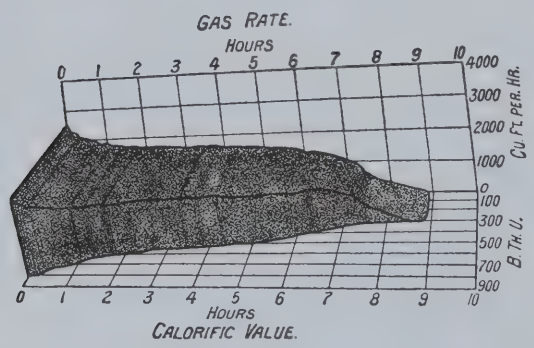


Fig. 7.

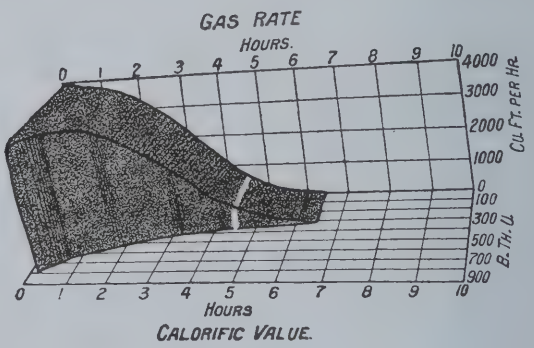


Fig. 8.

The yields up to the end of the sixth hour only are given. The volume and calorific value of the gases were represented as shown in Figs. 7 and 8, the figures having the general form of ox tongues. These results are well worth careful study, as it will be seen that at the end of 4½ hours the rate of evolution of gaseous therms was only 1½ per hour, and half-an-hour later it had fallen to half that rate. It would appear to be fairly obvious, therefore, that as many therms were being utilised in heating the retort setting as were being extracted from the coke after 4½ hours, hence the carbonising period might well be reduced by one-half.

When considered in conjunction with the other researches mentioned in this chapter, it is clear that, by the adoption of blending with or without briquetting, it is possible to operate gas retorts at a much higher rate of efficiency than is the rule at present. The maximum rate is attained in the earlier stages of coking, and every effort should be made to maintain that rate, and cut out the uneconomical period represented by the thin end of the tongue, as shown in Fig. 8.

What has been said with regard to gas manufacture in horizontal retorts applies also to intermittent vertical retorts and coke ovens. Often enough one finds that while coke oven managers are endeavouring to drive off all the volatile from the coke, the gases evolved in the later stages are allowed to escape into the atmosphere, as they are too "lean" to be passed through the recovery system. The object of the coke maker is to ensure that the middle of the charge reaches about 900° C. Now, bearing in mind that expert opinion favours a lower carbonising temperature (see Koppers, Sperr and Jacobsen), it appears that a needless waste of energy also takes place here.

Whether a coke made at a temperature between 650° and 800° C. will give good enough results in a blast furnace or not is at the moment immaterial since it does not affect our proposal, but it is quite certain that domestic consumers would prefer such a coke to that now supplied.

The writer has long held the view that semi-coke could be manufactured in coke ovens on a large scale, and he elaborated his proposals in 1925. The system proposed for the manufacture of semi-coke in bulk is the employment of 14-in. ovens operating under high-temperature conditions, with flue temperatures up to 1,400° C. or higher. In most cases blends of coking and non-coking coal with or without coke breeze should be used, the optimum blend being determined in the laboratory in every case. Uncompressed charges of suitably crushed coal, should be charged by top charging. The charges should be pushed when the temperature in the middle reaches about 600° C., and then quenched. Owing to the fact that volatiles would be coming off in quantity during the discharging operation, it would be necessary to discharge into suitable chambers.

The following are the conditions considered essential: (1) Maximum possible flue temperature; (2) Flue walls to be built of silica, or a better conducting refractory; (3) The employment of narrow ovens, preferably not more than 14ins. wide; (4) The use of coals or blends of coals having sufficient, but no excess, binder; (5) The ovens to be pushed when the middle of the charge in each case reaches about 600° C.

Although high flue temperatures are employed, the average carbonising temperatures will be in the region of 700° to 750° C., so that the product will not be a high-temperature fuel, but a medium-temperature semi-coke.

The full coking period for a 14-ton charge in a 14-in. oven is 11 hours, though this period will be considerably reduced when running for domestic fuel, so that the ovens would be discharged at least three times per 24 hours. In this manner, each oven should have a throughput of not less than 40 tons of coal, and 32 tons of semi-coke per oven day.

The system may also be employed with vertical chambers of convenient width, say 12 inches. Chambers of this type normally carbonise two charges per 24 hours, but if run for semi-coke, at least three charges could be carbonised per day provided non-swelling coals, preheated coals, or suitable blends were employed. Obviously, the make of gas per ton of coal would be reduced, but as the retorts would be run with each charge only during the period while high yields of gas were being evolved, that is to say they would be working at the highest rate of efficiency, a higher yield of gas per retort per day would be obtained.

There is no doubt that gas engineers can make semi-coke on existing plant with little special effort. In fact, it was recently found that one gas company in a Yorkshire town was unwittingly turning out large quantities of this material, which formed the bulk of the fuel that was being supplied as gas coke, and which burnt well on an open fire.

Another great advantage of this system of semi-coke manufacture is, that by simply reducing or prolonging the period of carbonising, a medium-temperature or a high-temperature fuel can be obtained at will, while maintaining the maximum temperatures in the retort flues, both in intermittent vertical retorts and in coke ovens.

Chapter 3.

THE PREPARATION OF COKE FOR THE MARKET.

By Frank S. Townend, B.Sc. (Eng.).

The coke available for sale on gasworks amounts in weight to approximately one half the weight of the coal carbonised, and its value provides a credit equal to approximately one half the cost of the coal. Its value to the gas engineer is, in fact, second only to that of the gas itself.

Some of the qualities looked for in gas coke by the consumer such as ash content, hardness, etc., depend on the nature of the coal from which it has been produced and the particular method of production, subjects which are dealt with elsewhere. Its size, moisture content, and to some extent its ash content can be controlled after the coke has been removed from the carbonising chamber.

Objects of the preparation of coke.

Whilst there is no standard specification to which gas coke is required to conform, the advisability of providing a coke with low moisture content and carefully graded as to size, is recognised. There is also in industrial districts a demand for a screened breeze washed free from " bats " and shaley particles. This chapter is, therefore, devoted to a consideration of the technique of the preparation of coke under three heads, viz.:—Section 1, Quenching and Cooling; Section 2, Screening and Grading; Section 3, Breaking and Washing.

QUENCHING AND COOLING COKE.

It has been considered desirable to retain the word *quenching* when referring to the use of water sprays, and *cooling* when steam or inert gases is the cooling medium.

In gasworks practice carbonisation is complete when the coke has attained a temperature of from 900 to 1,000° C. In this state the coke contains a considerable amount of sensible heat, the extent of which may be calculated as follows:—Sensible heat at temperature t° F. (above 32° F.) as B.Th.U.'s per lb. coke=mean specific heat (32° F. to t° F.) × (t − 32).

The values of the mean specific heat of coke from 32° F. to t° F., according to various authorities, are given in Fig. 1. Using curve 2, the amount of sensible heat contained by coke at various temperatures is shown in column 1 of Table I.

Table I.

Column	1	2	3
Temp.	Heat to be abstracted. B.Th.U.'s per lb.	Water at 60° F. to Steam at 212° F. lbs.	Water. Gals. per ton coke.
500° C.	182	.16	35.8
600° C.	252	.221	49.5
700° C.	324	.284	63.6
800° C.	398	.349	78.2
900° C.	476	.418	93.8
1,000° C.	551	.485	108.5
1,100° C.	625	.549	123.0

When at a temperature of 1,000° C. coke contains, as sensible heat, about 551 B.Th.U.'s per lb., this heat having been provided by the fuel burnt in the producers. What this amount of heat really means may be seen from the following statements. 551 B.Th.U.'s per lb. of coke is equivalent approximately to :—

4.3% of the total heat in the coke ;
3.0% ,, ,, ,, coal carbonised ;
20% ,, ,, ,, fuel used in the producers,

and has involved the consumption in the producers of at least ¾ cwt. of coke per ton of coal carbonised.

Amount of water required for quenching.

Universally, up to the introduction of the continuous vertical retort 25 years ago, and to a considerable extent at the present time, the sensible heat of the coke is absorbed by spraying the hot coke with water. Assuming that the water is turned into steam at 100° C., the theoretical amounts of water required to quench coke, from various temperatures to 100° C., is as given in column 3, Table I., from which it will be seen that, in gasworks' practice, quenching should be carried out theoretically by the use of 100 gallons of water per ton of coke, a perfectly dry coke being obtained as the result. In actual practice many times this amount of water is ordinarily used, a more or less wet coke being the outcome.

This very inefficient performance is due to several causes which may be noted as follows:—

(a) Poor distribution of the water, causing some portions of the coke to be over-quenched in order to quench adequately the remainder.

(b) General over-quenching, due to lack of control of the amount of water used.

(c) When a batch of coke, containing all sizes of pieces from 4in. and upwards down to dust, is sprayed with water, it is not possible, however careful the distribution of water may be, to avoid over-quenching the smaller sizes.

In addition, the clouds and steam and dust raised during the operation often prove a nuisance and a cause of deterioration of neighbouring structural steelwork, and of course the sensible heat of the coke is entirely lost. Since the more elaborate cooling systems described later, which eliminate the above disadvantages, may not, on score of capital cost, etc., be justified water quenching is likely to persist for many years, and it is proposed now to review the method which wide experience has shown to be the most satisfactory, of carrying out this operation, in order to avoid as far as possible the present troubles.

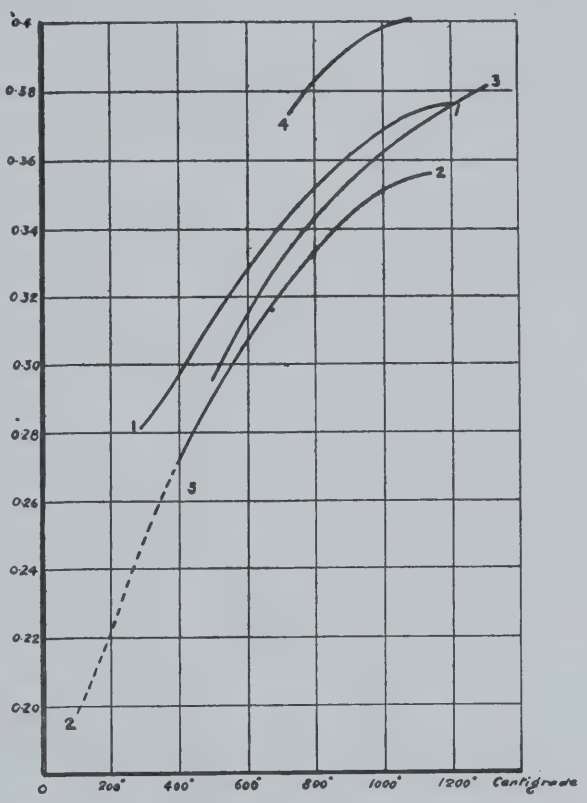


FIG. 1.—*Mean Specific Heat of Coke at Various Temperatures (F. Escher).*

1.—Coke-oven coke with 9.45% ash (Wohler).
2.— Do. do. do. 10% ash (Debrunner).
3.— Do. with 15% ash (Terres and Schaller).
4.— Do. (Otto, Breslau).

The method is that largely developed by the coking industry in America. It is in regular use on gasworks in that country, where coke ovens and intermittent vertical retorts are at work, and in a modified form is being installed on the intermittent vertical chamber and inclined chamber plants at gasworks in this country.

The complete scheme carries out the quenching in two stages, depicted in Fig. 2, which shows the arrangement at a coke oven plant. The red-hot coke is pushed or is dropped into a car which transports it under a specially built tower, where it is subjected to a strong spray of water, a known volume being used each time. After the car has drained for a few seconds, it travels alongside a sloping wharf on to which it deposits its burden in a fairly thin layer. The residual heat in the larger pieces of coke evaporates the surplus moisture, and a coke, the larger sizes of which have a moisture content of less than 2 per cent., can be obtained. Any portion of the charge which, through inadequate treatment may tend to fire, is quenched by hand on this wharf, from which the coke is ultimately fed to a conveyor and taken to the screening plant. Fig. 2 shows the quenching tower in connection with a battery of Becker coke ovens. On the intermittent vertical chamber plant at the Ramsgate gasworks the cooling wharf is omitted, the coke after being subjected under a quenching tower to a controlled spray of water, is drained, dropped into a hopper, from which it is drawn into the skip of an inclined hoist, final cooling taking place as the coke

passes to the top of the screening plant. On installations of inclined chambers, the quenching tower traverses the front of the bench of chambers and the hot coke drops directly into the coke car under the tower. Where, as in the last two instances, the wharf is omitted, a coke with a somewhat higher moisture content, namely below 5 per cent., is the result.

It will be observed that in all three types the amount of water used is under control, and further steam and dust are prevented from blowing round the carbonising plant. The amount of water used varies from 200 to 700 gallons per ton of coke.

Quenching on continuous vertical retorts.

The continuous vertical retort lends itself admirably to the production of a dry coke (less than 1 per cent. moisture may be obtained) without any steam nuisance, and with a recovery of the sensible heat of the coke in a useful and valuable form.

Fig. 3 shows the method of quenching on one well-known form of continuous retort. In this instance, application of heat to the descending charge ceases at a point 5 feet above the bottom of the retort. In its further descent some heat is given up to the secondary air flue (A) which passes alongside the retort. The bulk of the remainder of the sensible heat is absorbed in preheating steam and converting it into water gas, which ultimately passes away with the coal gas and is sent out for use in the town. The steam, either saturated or superheated, is introduced at two or more positions (B) in the curved plate. In addition to cooling by steam, a water spray is generally provided at (C) which may be used if the amount of steam admissible must be limited on account of the quality of gas to be made. The use of a small amount of water, also, is advantageous in preventing dust flying about when the coke is withdrawn from the coke hopper, perfectly dry coke often being rather dusty.

It should be placed to the credit of the continuous vertical retort that it embodies a method of coke cooling which involves practically no capital outlay, eliminates nuisance, recovers the heat of the coke in a most valuable form, i.e., of gas for distribution in the town, and provides a dry coke.

Fig. 2.—*Coke-quenching Station and Wharf.*

Independent dry cooling methods.

Where in carbonising plants such as horizontals, vertical or inclined chambers and coke ovens, the coke is removed from the coking chamber in a red hot state, and it is intended to produce a dry coke without the attendant disadvantages of quenching with water in the usual way, recourse must be had to one or other of the independent dry cooling plants which have been developed during the past few years. Basically, in all these systems the hot coke, after removal from the carbonising chamber, is immediately transported to an air-excluding chamber, in which the heat of the coke is absorbed by a cooling medium. These may be inert gases (nitrogen, carbon dioxide, etc.), as in the Sulzer, Collin and Koppers plants, or hot water (Heller-Bamag). After being raised in temperature, the cooling medium is passed through a waste heat boiler where it is cooled, the heat being usefully used in raising steam. Fig. 4 illustrates the Sulzer plant. In this system the hot coke is fed into the brick-lined chamber attached to a steam boiler. A fan keeps in circulation a current of inert gases which are really the products of combustion of the air entering the system when coke is put in, and which also is intro-

duced to make up for the reduced volume of circulating gases as cooling takes place. The amount of coke consumed is negligible. In practice, the amount of steam raised varies with the temperature of the coke, but may be taken as 700 to 900 lbs. of steam at 150 lbs. per sq. in. per ton of coke. The coke is removed from the chamber at a temperature of about 250° C., and is perfectly dry.

In the Heller-Bamag system, the hot coke is placed in a chamber and sprayed with water heated to a temperature of 140-150° C. The steam thus formed is allowed to build up in pressure to about 130 lbs., when it then escapes round the tubes of a steam boiler and afterwards through a water heater. In addition to the heat absorbed from the coke by converting the water to steam, some of the steam is converted into water gas, which is an endothermic process. It is claimed that the water gas produced has a calorific value of 298 B.Th.U.'s per cu. ft. and therefore can be mixed with the coal gas stream.

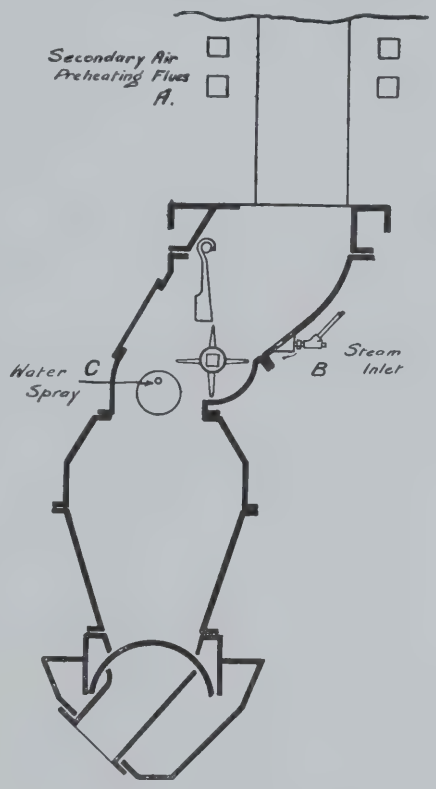


FIG. 3.

Economics of dry cooling.

It is obvious that the capital expenditure for independent dry cooling plants is considerable. Whether this will be justifiable depends largely on individual circumstances. In considering the economy of a dry cooling plant, the following headings of debits and credits should be evaluated.

Debits. (a) Interest and sinking fund on capital outlay; (b) labour cost; (c) water; (d) wear and tear; (e) loss of coke (this is generally negligible).

Credits. (1) Nett steam output of the boiler. As this will replace steam raised in a central boiler plant, it should be credited at the cost of steam raising in such plant, if the coke breeze thus released can be satisfactorily disposed of. (2) In the case of new works, the installation of a dry cooling plant may lead to a reduction in the size of the central boiler plant required, and the interest and sinking fund on such reduced capital outlay is a credit. (3) In the Heller-Bamag system the water gas which is mixed with the coal gas, stated to be about 5 therms per ton of coke, is also a credit. (4) The cost of water which would be required in a wet quenching plant.

It is also claimed that the amount of breeze to be disposed of is reduced by the adoption of dry cooling, and the ability to offer for sale an improved coke due to its dryness is an intangible but real credit.

COKE SCREENING AND GRADING.

The coke, as it is removed from the carbonising chamber, comprises pieces varying in size from, say, 6in. down to dust, the proportions of the different sizes varying according to the nature of the coal, its preparation before carbonising, the type of carbonising plant, etc.

In but few instances would such an "unscreened" coke give the best results to the consumer. Different purposes require different sizes of coke. In E. W. Smith's paper on "The Utilisation of Gas Coke" (Trans. R.S.A.) is given a very comprehensive list of industries in which coke is used, and the respective sizes of coke which are found to be most suitable. Naturally, the character of the local industries determines the demand for the various grades of coke, and hence practice in gasworks regarding the sizes in which coke is sold varies very considerably. In some cases the coke is sold without any further preparation as "unscreened coke." In other cases the unscreened coke is "forked" into carts or bags, which results in a proportion of the small coke and dust being left behind, for use mainly in the works' boilers. It is, however, recognised in many districts that the best interests of both consumers and gas undertakings are served by the offering of coke for sale which has been graded into several different sizes.

In various instances, where grading is in practice, the number of sizes and the gauge of each size varies as may be seen from the following table:—

London Coke Committee.		Birmingham Gas Department.	
No. 1. Large Grade Coke	over 2in.	Large Coke	over 2in.
No. 2. Broken or Domestic Coke ...	2in. to ¾in.	Small Coke	2in. to 1⅛in.
No. 3. Forge Coke or Coke Nuts ...	¾in. to ⅜in.	1in. Breeze	1½in. to 11/16in.
Coke Breeze	⅜in. to nil.	Bean Breeze	11/16in. to ⅜in.
(All screens are square mesh screens.)		Dust	⅜in. to nil.

The ⅜in. to nil material has a market value only about one-third that of the other sizes, and therefore the problem of coke screening may be summed up as the provision of different sizes of coke with as little outlay as is reasonable to expect, and with a minimum production of material ⅜in. to nil in size.

Principles of screening.

F. M. Birks has defined the operation of coke grading as follows:—"It must present each particle to a pre-determined gauge in two dimensions, through which the undersized pieces can pass without obstruction."

Bearing in mind the necessity of carrying out the operation without undue production of breeze and dust, the following principles may be formulated:—

(1) The feed to the screens must be regular. This applies particularly to the first screen in the series. The coke is often delivered to the screening plant in bulk quantities. If this be fed regularly to the first screen, the material passing over the subsequent screens will be more regular in quantity.

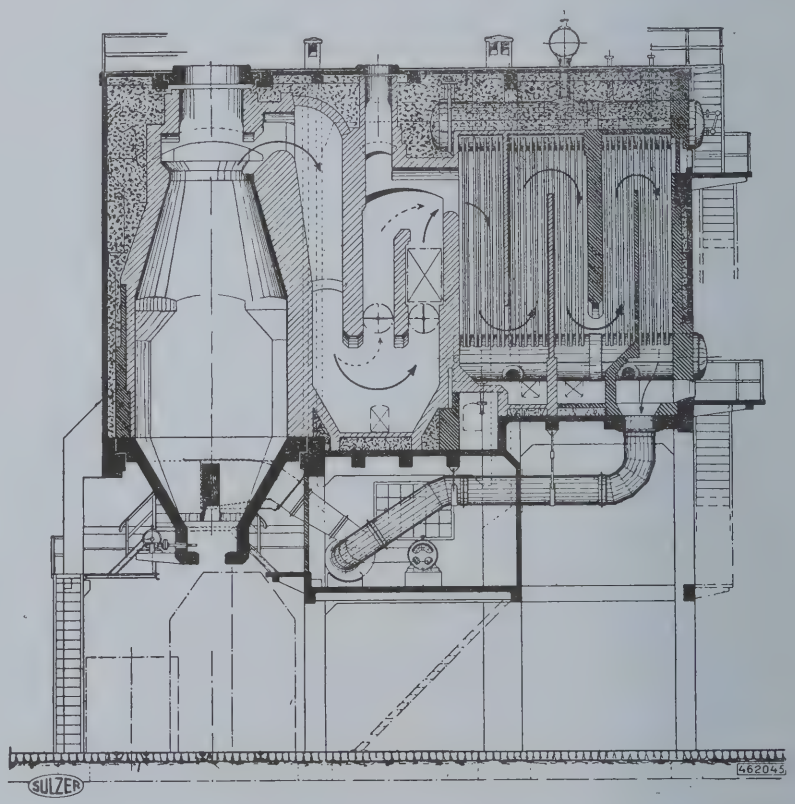


FIG. 4.—*Sulzer Coke-cooling Plant at Utrecht Gasworks.*

(2) All particles should, in turn, be permitted to come in contact with the screening surface, and therefore the stream of material, even with the largest grade, should not be more than 4in. thick.

(3) Also, the stream should be disturbed when on the screen to prevent the small particles being carried by the larger, but the disturbance should not be so violent as to break up the coke to breeze and dust.

(4) In passing from one screen to another, or from screen to storage bunker, all grades with the exception of the breeze to dust should not be subjected to extensive free vertical drops. The following rules are suggested:—

With large coke above 2in. maximum free vertical drop	1ft. 6in.
With coke 2in. to 1in. maximum free vertical drop	3ft. 0in.
With coke 1in. to ½in. maximum free vertical drop	6ft. 0in.

Flow diagram.

It is very general practice to pass the whole make of the coke over a series of screens of meshes gradually increasing in size, as shown diagrammatically in the upper part of Fig. 5.

This scheme has one important disadvantage. It is almost impossible to obtain efficient separation of the $\frac{3}{8}$in. to nil material, since the large pieces obstruct the screen and tend to carry the small with them, unless excessive disturbance of the stream is resorted to. It is found preferable to adopt the scheme shown diagrammatically in the lower part of Fig. 5.

In this case, the unscreened coke is "scalped" over a 2-in. screen and a clean plus 2-in. product obtained. The undersize 2-in. material then passes over the remaining screens and a much better separation of the $\frac{3}{8}$in. to nil results.

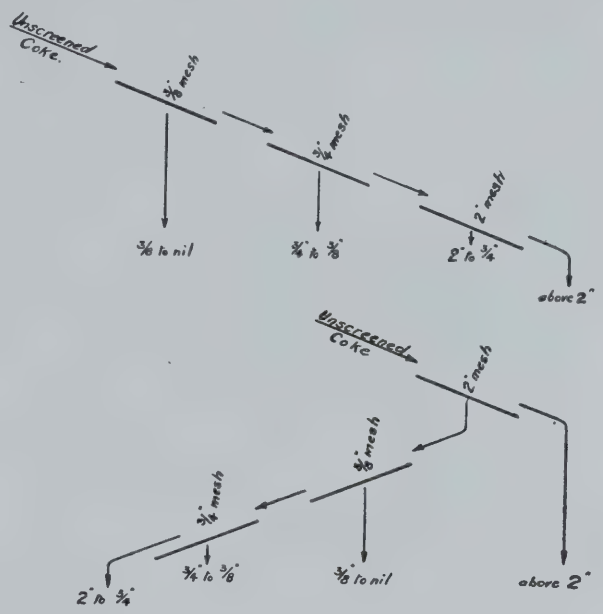


FIG. 5.—*Flow Diagrams for Coke Screening.*

Gauging.

The gauge to which the particles are presented may be either the openings between parallel bars, or meshes, rectangular, square or round in cross-section. The character of the product passing through and the amount will vary accordingly.

A piece of coke may be considered as three dimensional. Comparing the character of the undersize material passing the 1-in. meshes of the four types mentioned, we find:—Passing 1-in. round mesh maximum 1in. spherical; passing 1in. square mesh maximum, say, $1\frac{1}{4}$in.×1in.×$\frac{1}{4}$in.; passing 1in.×3in. rectangular maximum 1in.×1in.×3in.; passing 1in. bar screen maximum 1in.×1in.× unlimited.

FIG. 6.—*Cataract Grizzly Screen combined with Coke Cutter.*

It is clear that the three last screens will pass a greater proportion of the coke to be screened than the first, but there will be a much greater range of sizes. In actual combustion, however, a piece of coke 1in.×1in.×3in. will approximate in behaviour to a 1-in. spherical piece rather than a 3-in. spherical. But the voids in a coke bed, comprising 1-in. spherical pieces, will be greater than those in a bed consisting of a mixture of 1-in. spherical and 1in.×1in.×3in. pieces. It can be taken as a practical basis, that for very accurate grading, a round or square mesh is necessary. For reasonably accurate grading, combined with a greater proportion of the undersize, the rectangular mesh is required, whilst the bar screen, whilst giving a still larger amount of undersize product, provides an oversize coke of generally larger dimensions, and an undersize much less accurately graded. In practice, a square mesh can give the same product as a round mesh, and the relative dimensions may be obtained from the following table.

Square.			Circle.			Square.			Circle.
¾in.	...	...	⅞in.	...	...	2in.	...	...	2¼in.
1in.	...	...	1⅛in.	...	...	2½in.	...	...	2-13/16in.
1¼in.	...	...	1-7/16in.	...	...	3in.	...	...	3⅜in.
1½in.	...	...	1-11/16in.	...	...	3½in.	...	...	3-15/16in.
1¾in.	...	...	2in.	...	...	4in.	...	...	4½in.

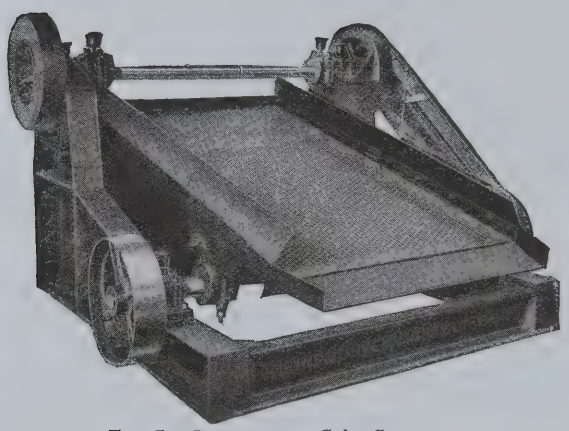


FIG. 7.—*Reciprocating Coke Screen.*

Screen Plates and Sieves.

The meshes may be formed by bars, punched holes in plates, or by woven wire cloth. Woven wire cloth has a considerably greater discharge area per sq. ft. of screening surface than a punched plate of equal mesh. It is claimed that the increase in the size of the mesh through wear during use, is not so great with wire cloth, and that accurate sizing is retained for a longer period. Wire cloth should be "double crimped," so that the individual wires cannot move and inaccurate gauging result.

TYPES OF SCREENS.

The principles of screening already mentioned are embodied in various ways in a large number of commercial types of screens. Generally the engineer gauges the suitability of any particular screen by (a) the efficiency with which it separates its required fraction; (b) its capacity per unit of floor space; (c) the head-room required; and (d) its tendency to produce breeze. It is proposed briefly to indicate the outstanding characteristics of the screens most commonly used.

Screens for large sizes.

Revolving Screens. This type is very usually found in English gasworks. It is too familiar to require description. From the point of view of efficient grading it leaves something to be desired, as if run too slowly the stream of material is not disturbed enough to obtain a clean separation of the various fractions, and if run too quickly considerable breakage of the coke may take place. It requires considerable head room and specially curved perforated plates or wire cloth. With the greater attention being given to-day to the preparation of coke, it is becoming more generally recognised that the types reviewed below possess greater advantages towards more efficient and economical screening.

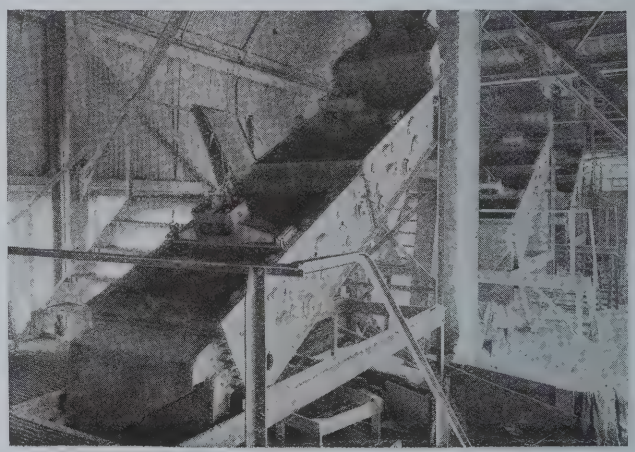


FIG. 8.—*Hum-mer Vibratory Screens.*

"*Marcus*" *Reciprocating Screen.* This consists of a long horizontal trough which is reciprocated "to and fro" by a balanced motion and propels the material forward in a thin layer. The base of the trough is formed of a series of plates perforated with holes of increasing size corresponding to the various gradings of screened product required. This apparatus requires little head room and produces little breeze. The floor space for a given throughput is rather considerable. Its efficiency of separation is high. A notable installation is that at the Waddon gasworks, Croydon.

"*Cataract Grizzly*" *Screen.* This apparatus (Fig. 6) consists of a series of shafts set in a cast-iron bed which lies at an angle of about 20° to the horizontal. On the shafts are mounted a series of discs with irregular periphery. The screening openings are formed between the discs and the shafts, and are square. The shafts are driven in the direction of the flow of coke at different speeds, the slowest being at the top. The material to be screened is delivered at the top of the "grizzly" with as little velocity as possible. This type of screen may be used for accurate screening from $\frac{3}{4}$in. to 4in. and possesses high capacity for small ground space. It does not require very much head room and is economical from the point of view of breeze production. The following particulars relate to the Robins Cataract Grizzly.

Size of square openings.	No. of shafts.	Dia. of discs.	Width of screen surface.	Capacity in tons per hour fed to screen.	H.P. drive.	Overall length	Height to top of discs.
$\frac{3}{4}$in. to $1\frac{1}{2}$in.	8	$9\frac{1}{2}$	24in.	75	5	6ft. 3in.	2ft. $6\frac{3}{8}$in.
$1\frac{5}{8}$in. to $2\frac{1}{2}$in.	5	15	24in.	75	5	6ft. 3in.	2ft. 7in.
$2\frac{3}{4}$in. to 4 in.	5	18	24in.	75	5	7ft. 0in.	3ft. $5\frac{1}{2}$in.
The capacity is increased proportionately by widening the screen.							

"*Whitehall*" *Bar Screen.* The bed of the screen is formed of T section bars, spaced at the required distance apart. If several separations are required, the distance between the bars is varied in the length of the screen. The bars are made of steel or cast iron, and are simply dropped into slotted frames. The material is partly carried, and partly pushed along the screen, by blades set at a particular inclination to the screen, and the material is gently turned over by light chains as it passes along the screen, to free dust and small from larger pieces. It is doubtful, however, if this screen gives quite as clean a separation as other screens for large coke. The headroom required is small, and the screen is especially suitable where it is necessary to distribute the material into a series of hoppers.

Screens for intermediate and small sizes.

When screening intermediate and small sizes, it is most important that the stream of coke should be adequately disturbed so that clean screening can be attained, and this is most efficiently carried out by shaking or vibrating the screen cloth.

Robins "Superflex" Screen. Made with openings in the screen plate $\frac{1}{2}$in. to $1\frac{1}{2}$in. inclusive, this screen consists of an inclined screen plate supported at top and bottom by two shafts driven by roller chain transmission (Fig. 7). Each shaft carries two short-throw eccentrics, set so that the screen plates travel in a circular orbit. Counterweight balance wheels absorb the vibrating forces of the screen within itself. The overall width is 7ft. $6\frac{1}{2}$in., overall length about 7ft., and the headroom required is 4ft. $6\frac{1}{2}$in. The capacity is 100 tons per hour with a 5-H.P. motor.

Vibrating Screens. There are several forms of this type of screen such as the Hummer, Vibrex, Sturtevant, Leahy, Mitchell, and Huwood, of which the first named is illustrated in Fig. 8.

Essentially, they all consist of a wire screen cloth which is kept in a state of rapid vibration. The material is delivered to the top of the screen, the inclination of which is arranged so that the material proceeds downwards in a series of rapid but short "hops." In some of the forms mentioned, the screen cloth is held fast at the edges, the centre being plucked by either electrical or mechanical means. In others, the whole of the screen cloth and frame is vibrated. In the Hummer screen, the screen is held under "drum head tension," the centre of the screen being rapidly vibrated by an electro-magnet supported on a cross head above the screen cloth. In the Vibrex screen, the screen cloth and frame are supported on shock-absorbing springs, and the vibration is obtained from an unbalanced pulley which spans the frame. In other forms, the vibration is obtained variously, by a rotating cam shaft and tappet, an unbalanced armature or by a motor, balanced, but on eccentric ball bearings. Vibrating screens, whilst being applicable to the screening of all sizes up to $1\frac{1}{2}$in., are particularly suitable for small sizes.

General considerations.

If the coke is delivered to the screening plant in bulk, say by telpher, it is necessary to receive it in a hopper and feed the first screen through a control gate or by an automatic feeding device. If the vertical distance between successive screens is considerable, it is better to have a series of short flights, rather than one long chute connecting them. The velocity of the material on reaching the screen is thus kept low. Direct vertical drops should, as far as possible, be eliminated. The angle at which chutes require to be placed depends on the size and dryness of the coke, and the following experimental data of S. E. Whitehead is useful in this connection.

Coke Sliding Upon.	Friction Angle. θ	Coefficient of Friction, μ=tan θ.
	Degs.	
Rusty mild-steel plate ...	28	0.53
Clean cast-iron plate	26	0.48
Black sheet iron	20	0.36
Firebrick	29	0.55
Concrete	27	0.51
Staffordshire blue brick...	26½	0.50
Staffordshire brindled brick	27	0.51
Slate	28	0.54

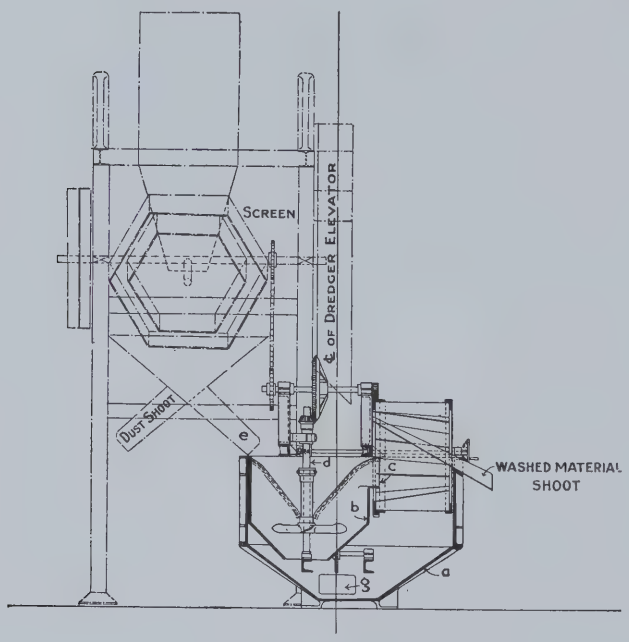


FIG. 9.—"*Retriever*" *Coke Washing Plant.*

In delivering a screened product into storage bunkers, consideration should be given to the avoidance of subjecting the coke to severe free vertical drops. Spiral chutes, etc., have been used.

Re-screening.

The maintenance of a satisfactory sale for a particular grade of coke depends on sending out a product free from smaller coke. It may be that the subsequent handling of the screened product from screens into bunkers, and the movement of coke down to the bunker outlet produces an excessive amount of smalls. If this cannot be avoided it will probably be desirable to re-screen the coke as it is drawn from the hopper into trucks, bags, etc.

Loading.

For a similar reason, consideration might be given with advantage, to the means of delivering the coke into trucks and carts. Loading booms, which are in effect belt conveyors, and the delivery end of which may be lowered into the truck, are used on coking plants where the size of the trucks permits of its operation. In this country, where small trucks are mostly used, some form of movable delivery chute does not appear impracticable. If steps are taken at the gasworks to deliver into the truck a clean product, the responsibility of the engineer as to the delivery of a satisfactory product to the consumer, ends.

COKE BREAKING AND WASHING.

The most suitable grade of coke for use in open domestic fires is approximately 1in. to 2in. size. The demand for this grade is increasing, and often outstrips the amount rendered available simply by screening the coke. The deficiency may be met by cutting the large coke. Coke breakers may be obtained in sizes from 10 to 40 tons per hour. The essential features required are, firstly that the action of the cutters should be *shearing* rather than *crushing* in order to reduce the amount of dust produced; secondly, coke having an extremely abrasive action on iron, the cutting rolls must be made of very hard material (generally chilled castings), and should be readily removable for replacement. The best position for

the breaker is at the outlet of the large coke screen, the coke, after cutting, being returned to the screening plant for grading into the smaller sizes.

Coke washing.

The smaller sizes of coke, say ¾in. downwards, often have a high ash content. This is due to the fact that when only roughly crushed coal is carbonised, the shaley matter (bats) form projections on the large pieces of coke, and during handling and screening break away, ultimately finding their way with the small coke. Though this results in the ash content of the large coke being reduced, often by as much as 1 to 2 per cent., it renders the small less acceptable for forge, smithy and other metallurgical purposes. Since the shale is heavier than the coke, it is possible to wash the coke, and one form of coke breeze washer is illustrated in Fig. 9. The coke to be washed must be first freed from dust. The washer consists of a tank (a) having an inner compartment (b). This has a coned bottom which, being open, forms a restricted orifice. The top of the inner tank is provided with an overflow weir (c). A vertical propeller shaft is fitted in the inner tank. Water is introduced into the outer tank, the rotation of the impeller causing a continuous circulation of the water from the outer tank, through restricted orifice, up the inner tank, and over the weir. The coke to be washed is delivered on to the surface of the water in the inner tank, the clean coke being buoyed up over the weir and the dross falling to the bottom of the outer tank, whence it is removed by a bucket elevator. The clean coke is delivered into a rotating ejector which delivers it on to a washed coke chute.

Whilst the provision of screening plant entails an appreciable capital outlay, it is found in practice that graded coke can be sold at a sufficiently enhanced price to cover the extra cost involved. In London, graded coke is sold at one penny per cwt. more than ungraded coke, and washed and graded coke at another penny per cwt. On an annual sale of 25,000 tons of coke, one penny per cwt. equals £2,080. Considering two-thirds of this as required to meet the cost of labour and repairs, the remaining £700 will permit of a capital expenditure of £8,400.

Chapter 4.

THE USE OF GAS COKE IN INDUSTRY.

By E. W. L. Nicol, Assoc.I.C.E., A.M.I.E.E., M.I.Mar.E.

The greatest potential outlet for gas coke is, probably, as a steam-raising fuel. The fact, however, that steam boilers and mechanical stokers had been developed, and their output rated upon a free-burning coal-fuel basis, constituted a serious obstacle to the early adoption of coke, which, in certain circumstances, is a relatively slow-burning fuel.

This obstacle was largely overcome in the case of many hand-fired boilers by the introduction of modern impelled-draught apparatus, to supplement the natural draught system, which was then, and probable still is, the only system of draught control available in most boiler plants.

In the case of boilers equipped with natural-draught mechanical chain-grate stokers, which were by far the most commonly used in large industrial and electricity supply stations, and which are, essentially, coal-burning stokers, the use of coke, or any considerable admixture of coke, was proved to be impracticable. The introduction by the present writer of a simple modification to this type of mechanical stoker, known as the patent Sandwich system, which enabled coke and coal to be fed to the boiler furnaces in super-imposed layers of about equal weight, successfully overcame the difficulty of using coke on natural-draught chain-grate stokers.

But in all cases dealt with, the onus of devising ways and means of utilising coke as fuel for steam raising, and of proving it to be equally effective, and, at the same time, more economical than coal in maintaining the required head of steam lay with the London Coke Committee; and it is due mainly to their action that coke has been successfully introduced and is now used by a large number of steam users, including manufacturers and public utility authorities.

Although the use of gas coke as fuel for steam raising has effected financial economies sufficiently substantial in certain cases to warrant its retention in preference to coal, its introduction for this purpose has an important bearing upon the question of fuel economy, in the wider sense, which does not directly concern the ordinary fuel user.

The additional advantage of smokeless combustion, incidental to the use of gas coke as fuel, although rightly regarded as valuable from the national view-point, is not necessarily so regarded by industrialists; and this characteristic of gas coke is not always taken into account in appraising the relative commercial values of coal and coke.

The economic advantages which would accrue from using smokeless gas coke in lieu of raw coal for all hand-fired boilers are, however, fully recognised; and by the use of coke, or coke breeze, on the Sandwich system, it is claimed that, in addition to these advantages, coal of a relatively low grade, usually regarded as unsuitable, and often unsaleable, may be used in its natural state efficiently and economically. An important outlet is thus provided for the solid residual from modern carbonisation processes, as well as for increasing the demand for a waste product, amounting to about 25 per cent. of the total output of the coal industry.

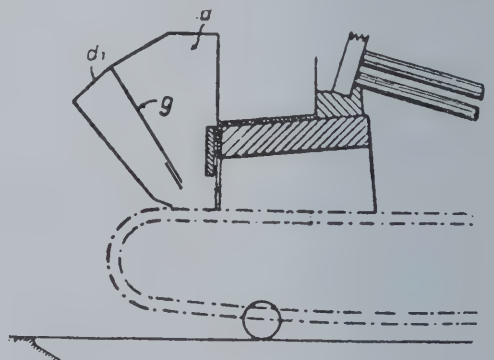


Fig. 1.—*Sketch shewing Sandwich system of feeding Coke and Coal with Chain-grate Stoker.*

Reference to Fig. 1 will show the extreme simplicity of this system. From a divided feed hopper coke is fed on to the moving grate in a layer of any required thickness from hopper d_1. From the hopper d, low-grade coal slack is fed on top of the coke layer, the proportion of coal being regulated by means of the guillotine door in the usual manner. Thus, the composite feed enters the furnace in well-defined super-imposed layers, the coal being on top. The volatile gases given off from the latter maintain the

firebrick ignition or "coking" arch in an incandescent state, thus establishing positive and continuous ignition of the coke at the point of entry on the grate. With this system, the fine coal is borne on top of the porous coke layer, and it is not only burned completely, but produces no appreciable smoke.

Coke-fired Power Stations.

One or two instances may be cited indicating the sound basis upon which the Sandwich system of burning coke and coke breeze has been instituted in this country.

Equipped with this system, as an emergency measure, towards the end of the war, one power station in London had consumed some 300,000 tons of coke breeze at the rate of about 40,000 tons a year, a quantity equal to about half its total fuel consumption; and upon the strength of this experience a new boiler house at this station has been fully equipped with divided overhead coal and coke bunkers and Sandwich system chain-grate stokers. Its adoption in this case has been stated to be influenced by the fact that by this means the very friable small coal, from the recently developed Kent coalfield, can be used efficiently on chain-grate stokers. This coalfield is the nearest to London; and London needs, on the average, 50,000 tons of coal a day; so that to utilise economically the smalls, unavoidably produced at the pits, is obviously a matter of great economic importance.

In the new super-power station at Barton, Manchester, the boilers, each of 100,000 lbs. per hour capacity, give their full normal output with 50 per cent. of coke breeze fired on the Sandwich system. The overall efficiency is 84 per cent., which is equal to that obtained with coal alone, but of a slightly higher calorific value, according to comparative test figures obtained.

Further instances could be given—including that of a power station which has also claimed the lowest recorded fuel cost per unit generated—where this simple adaptation of the chain-grate stoker to use coke breeze and coal slack has successfully been adopted at power stations and at factories, collieries, etc.

Hand-fired Power Stations.

In the industrial field, and apart from central heating, the greatest demand for coke is now, probably, as a smokeless substitute for the higher grades of steam coal commonly used for power purposes and institutional work. The factors which govern power and steam production costs are now more thoroughly appreciated; and where pass-out steam or exhaust steam is required for heating or process work, as in most institutions and many industries, the independent steam plant has fully justified its continued use, as in these circumstances power and lighting can often be obtained almost as a by-product.

As fuel for the Lancashire boiler, which is by far the most commonly used in this country, coke is frequently forced into competition with bituminous coal; and as evidence of its economic value the case of Tooting Bec Hospital may be cited, as figures relating to the efficiency of the boiler plant at this important institution are regularly recorded and have recently been published by an independent authority.

In 1916, a test was carried out at this hospital with a view to introducing gas coke as a substitute for the hard steam coal then in use. This coal gave an equivalent evaporation of 8 to 9 lb. per lb. of coal. The yearly fuel consumption was then about 3,000 tons.

The average evaporation obtained during the trial with coke exclusively as fuel was 10.7 lb. Coke has since been in almost constant use; and the diagram (Fig. 2) shows that the evaporation obtained throughout 1925 (24 hours per day) averaged well over 10 lb. per 1 lb. of coke, showing that the results obtained on the original day-load test have been fully maintained.

The coke employed is remarkably free from moisture; this being in the region of 3 per cent. The proportion of ash is about 13 per cent.; 5,000 lb. evaporation, per boiler, per hour, can be attained; the depth of fuel in the furnaces is from 8 to 9 in., which has been found to be the depth giving the most economical results in firing coke. This fuel, while giving a high radiant heat, has not the disadvantage of coal, in that no soot is deposited on the boiler tubes and plates, and the necessity for frequent cleaning is eliminated.

Draught required for Gas Coke.

A point which will be of interest to coke users is that of the draught employed. It is found that the best results are obtained by having the damper only one-quarter open. This provides sufficient draught to secure the necessary combustion of the coke, with natural draught, in spite of the low temperature at the base of the stack, which averages only 240° F. The temperature of the feed water is increased 70° F. in the economisers by a drop in flue gas temperature of 160° F.

In a plant of this type (4.30-ft. by 8-ft. Lancashire boilers) where a fairly regular load is carried, coke of a satisfactory character shows to a greater advantage, both in regard to evaporative efficiency and also from a financial point of view, than coal of high grade. The boilers are fitted with steam-jet forced draught furnaces, but are usually operated under natural draught.

Central Heating.

For use in low-pressure central heating boilers, gas coke is now regarded as almost indispensable. The conditions of service are exacting, and complete flexibility of control is imperative if convenience of operation and economy in fuel consumption are to be maintained. These conditions necessitate fairly even grading, to facilitate banking over long periods—frequently from Saturday to Monday—and a low volatile content, together with a satisfactory reactivity to ensure complete control and to prevent fouling of the heating surfaces. It is claimed that gas coke is the only fuel generally available possessing these

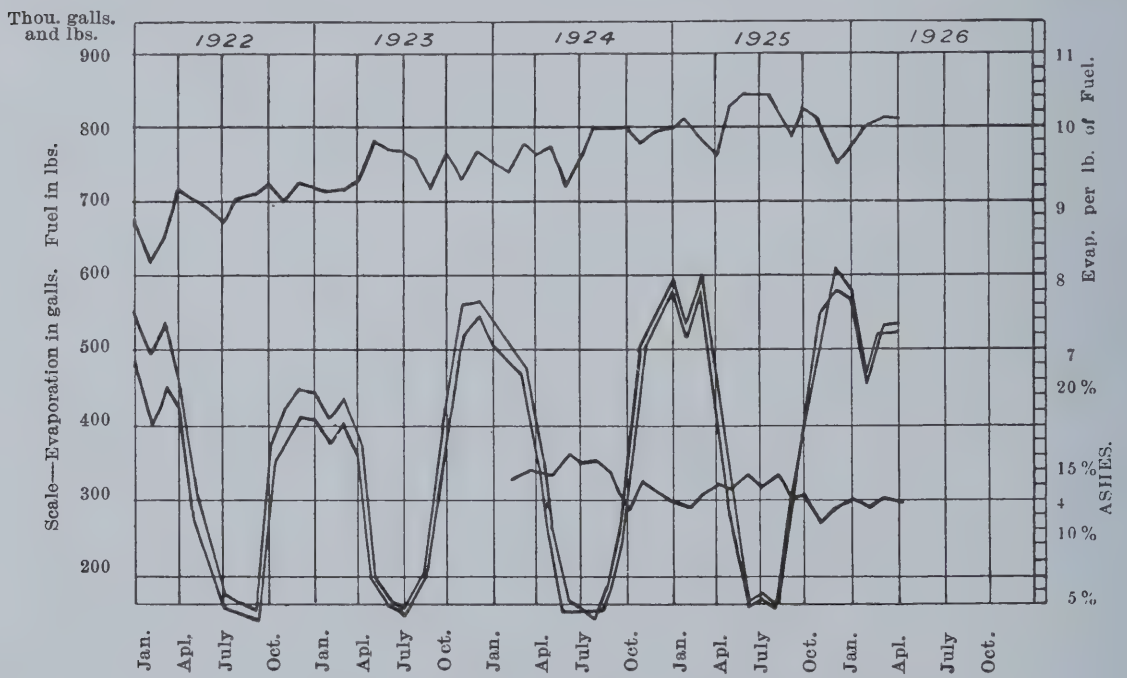


FIG. 2.—1. *Monthly evaporations (total) in gallons.* 3. *Monthly evaporation per lb. of fuel.*
2. *Monthly fuel consumption (total) in lbs.* 4. *Monthly per cent. ashes.*

characteristics. In certain isolated cases, oil fuel has displaced coke in central heating boilers; but only where conditions of use preclude the handling of solid fuel, or where the cost of operation is a secondary consideration.

In other cases, especially where the boilers are operated at, or occasionally over, their full normal capacity, expensive Welsh coal of the highest calorific power has been considered necessary in order to maintain the required output. One such case was the new County Hall, London, where coal of this description was in use, and the following details of official trials with Welsh coal and coke afford interesting evidence of the comparative thermal and commercial efficiencies of ordinary gas coke and coal of the highest quality.

Reduced temperature of flue cases.

Owing to restricted space, it was not possible to include economisers in the heating plant at the County Hall, so that in using Welsh coal it was found, during periods of heavy load on the boilers, that the temperature of the waste flue gases was as high as 950°. These hot gases leaving the chimney often caused trouble, and the question of lengthening the chimney shaft was considered; but one result of introducing coke at this juncture was a reduction of the temperature of the waste combustion products to the neighbourhood of 500° at full load, so that the necessity for raising the chimney shaft was entirely obviated.

This result was in itself of considerable moment; but the saving in fuel costs effected by substituting gas coke for coal was of far greater importance.

TABLE I.—COMPARATIVE ECONOMIC EFFICIENCY OF WELSH STEAM COAL AND GAS COKE AT THE COUNTY HALL, LONDON, S.E.

Welsh Coal.				Gas Coke.			
Date, 1925.	Tonnage, 24 Hours.	Lowest Atmos. Temp.	Fuel Cost.	Date, 1925.	Tonnage, 24 Hours.	Lowest Atmos. Temp.	Fuel Cost.
	T. Cwt.	°Fahr.	£ s. d.		T. Cwt.	°Fahr.	£ s. d.
Feb. 21	10 4	36	23 9 2	Mar. 10	13 5	30	22 12 8
,, 22	10 4	38	23 9 2	,, 11	12 11	32	21 8 9
,, 23	11 2	36	25 10 7	,, 12	14 10	28	23 18 4
,, 24	11 5	37	25 17 6	,, 13	13 16	34	23 11 6
,, 25	11 5	42	25 17 6	,, 14	13 17	35	23 13 2
,, 26	10 6	42	23 13 9	,, 15	13 2	42	22 7 7
,, 27	10 15	42	24 14 6	,, 16	11 19	39	20 8 4
,, 28	10 10	40	24 3 0	,, 17	11 9	43	19 11 3
Mar. 1	10 8	40	23 16 1	,, 18	11 13	32	19 18 0
,, 2	10 12	38	24 7 7	,, 19	12 0	36	20 10 0
,, 3	10 10	38	24 3 0	,, 20	11 3	46	19 0 11
,, 4	10 14	38	24 12 3	,, 21	11 19	34	20 8 4
,, 5	10 10	42	24 3 0	,, 22	11 14	32	19 19 8
,, 6	10 1	42	23 2 3	,, 23	11 15	32	20 1 4
Total ..	148 6	39.3 Aver.	340 19 4	Total ..	174 16	35.3 Aver.	297 9 10

Av. lbs. water circulated per 24 hours: Av. temp. rise:

Coal	14,906,600	Coal	15.61° Fahr.
Coke	15,300,000	Coke	17.15° Fahr.

Welsh steam coal cost (14 days)	£340 0 0
Gas coke cost (14 days)	297 0 0
	£43 0 0
Gross saving per week	£21 10 0
Allow for extra ash removal.....	1 10 0
Net saving per week	£20 0 0

According to figures published an actual monetary saving (based on prices ruling at the date of the tests) of £20 per week has been effected. Table I. shows also that the prevailing atmospheric temperature was much lower during the coke test, which would account for the increase in tonnage fired.

TABLE II.—DETAILS OF WELSH COAL AND GAS COKE TEST RESULTS—COUNTY HALL, LONDON.

Duration of Test.	Av. CO.	Av. Flue Temp.	Av. Thermal Efficiency.
	Per cent.	Fahr.	Per cent.
Gas Coke. 72 hours, 3 boilers.	14.5	464	82.0
,, ,, 85 ,, 2 ,,	17.8	516	86.0
Welsh coal. 72 ,, 2 ,,	15.6	531 to 950	82.5

Average thermal efficiency over continuous test period of 80.5 hours with coke as fuel ...	84.1 per cent.
Average CO_2 ditto	16.15 ,,
Average flue temp. ditto	490° Fahr.
Average cost ditto	18.34d. per 1 million B.Th.U.

Radiant value of gas coke.

The remarkable drop in the outlet of final temperature of the flue gases, amounting to over 400° F., when gas coke was substituted for Welsh coal, calls for special comment, as it proves coke's relatively high

radiant efficiency. Had the competing fuel been ordinary bituminous coal or " smokeless fuel " containing a higher percentage of hydrogen and hydro carbons, and less fixed carbon, the difference would undoubtedly have been greater, under similar load conditions. As it is, a net gain in efficiency of 1.5 per cent. was recorded, over a continuous test period of 80.5 hours, in favour of gas coke as compared with what is generally regarded as the most efficient coal produced in this or any other country; and this result was obtained under natural draught conditions, similar but more strenuous conditions of load, and without alteration to the boiler furnaces.

Bearing upon this question of fuel efficiency and the value of direct radiation in steam-boiler practice, the Fuel Research Board says that " Coke gives more radiant heat than coal of higher calorific value." The chief characteristics of gas coke in process of active combustion are, as is well known, intense radiation and carbonic oxide flame; and in the possession of these characteristics and in its freedom from hydrogen, gas coke is unexcelled by any other fuel. Gas coke of average quality contains 85 to 90 per cent. of fixed carbon—the most important of all fuel constituents—and by far the greatest portion of the heat developed by the combustion of coke is radiated.

Minimum excess air.

Another interesting feature of the L.C.C. tests is the high proportion of CO_2 maintained continuously, night and day, in the boiler flue gases—proving that coke can be consumed efficiently, at an economic rate, under natural draught conditions, and in its natural and untreated state, with a minimum excess of air (probably less than that required, under similar conditions, by any other solid fuel). The resulting high temperature head developed in the boiler furnaces enabled coke to maintain the full normal and overload output of the boilers, i.e., 5 million and 7 million B.Th.U. per hour per boiler.

With a total heating surface of only 869 sq. ft. per boiler the result is equivalent to a maximum heat transfer of over 8,000 B.Th.U. per sq. ft. of heating surface, per hour, a figure rarely exceeded in hand-fired natural-draught steam boiler practice; while, at the same time, an average efficiency of 86 per cent. was recorded over a test period of 8.5 hours.

The following are details of analyses and calorific values of the Welsh coal and gas coke used.

	Welsh Coal.	Gas Coke. Sample No. 1.	Sample No. 2.	Sample No. 3.
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture	1.6	8.72	8.75	1.75
Volatile	10.82	1.75	2.09	1.18
Fixed carbon	79.47	80.48	80.13	88.09
Ash	8.1	9.05	9.03	8.98

	Welsh Coal.	Gas Coke.
Gross calorific value ...	14.070 B.Th.U.	12,130 B.Th.U. av.
Sulphur content	0.7 per cent.	0.9 per cent.

Although not uncommon, the high efficiencies obtained with both Welsh coal and coke on these tests are not only a measure of the relative commercial values of these two fuels, which often meet in competition, but indicate that, by reasonable care and supervision, the efficiency of the comparatively small hand-fired boiler plant can be made to approach that of the largest power stations fired by mechanical stokers, or pulverised fuel.

The use of coke as fuel for small, or relatively small, steam boilers of the Cochran vertical type, commonly found in small factories and steam laundries, is now so general as to call for no further proof of its suitability and economy. The case of one laundry may, however, be mentioned as indicating and

confirming again the comparative values of Welsh coal and gas coke. At this laundry, Welsh coal had been used in a large Cochran boiler because it was believed that no other fuel would maintain the head of steam required. The weekly coal consumption averaged over a long period 7 tons. Substituting coke for coal the average consumption, over a period of many months, was 6 tons per week—a clear saving of over 50 tons a year, in addition to the difference in price per ton. The coke used was supplied by a London gas company.

Road transport.

One result of increased railway rates has been to divert to our highways an ever-increasing volume of long-distance goods traffic; and apart from the relatively high price of fuel for petrol motors, the steam wagon has been found to be very satisfactory for heavy haulage. In organising motor transport, an adequate, reliable, and cheap supply of fuel is, of course, a factor of paramount importance; and for steam wagons, smokeless combustion is a *sine qua non*. Gas coke, which is smokeless, is produced in suitable form for this purpose at some 1,600 gas works located in every city, township, and village. From these works, and from many local services, the bunkers of steam wagons can be replenished on any inter-city or country journey, usually without deviation from the route, or undue loss of time.

Thousands of steam vehicles are running in this country on coke exclusively, and their number is increasing. The secret of success—from a coke-burning point of view—is the design of the boiler fire-grate. The fire-grate area provided is amply large and has specially wide air spaces between the bars.

The actual financial economy of using coke in a steam wagon depends, of course, on the relative price and quality of gas coke and Welsh coal in each district; but that a great deal of work can be done upon a very small quantity of gas coke is proved by the records of the work and fuel costs kept by numerous users of steam wagons in all parts of the country.

There can be little doubt that the use of gas coke for steam raising would be considerably increased if a greater uniformity was obtained in the quality of the gas works product. Unfortunately, gas practice differs widely in the matter of quenching, the result being that in certain instances the high moisture content precludes the use of coke for this purpose. It is appreciated that it would be to the financial interest of gas undertakings to pay greater attention to this point, and modern gas practice is undoubtedly tending towards the production of a graded smokeless solid fuel containing a minimum percentage of ash and moisture, which should satisfy the most exacting requirements of industrial and domestic users.

PART V.—LOW-TEMPERATURE CARBONISATION.

Chapter 1.

PRINCIPLES OF THE PROCESS AND ITS ECONOMICAL AND INDUSTRIAL ASPECTS.

By Norman J. Bowater, O.B.E., B.Sc. (Eng.), A.M.Inst.C.E.

Low temperature distillation of coal, although only prominently before the public during recent years, is by no means a new invention or idea.

The gas industry, in its early days, employed low temperature, or semi-low temperature distillation methods, owing to the fact that they operated at that time with iron retorts, unable to stand more than about 700° C., and even at that temperature, having a very short life. It was only on the introduction of fireclay retorts, due to the realisation that the higher the temperature of carbonisation, or distillation, the greater the volume of coal gas evolved, that high temperature distillation came into its own and eventually became universal.

In the early days of the gas industry, gas was, as it is to-day, the prime consideration of the process. Such products as the coke, tars, etc., were looked upon as a necessary evil, and even to-day are spoken of as residuals, due to the higher price realisable for the gaseous products of distillation, than for the solid and liquid products. In recent years, however, more attention has been given to these residuals, owing to the importance that oil or liquid fuels have acquired, and the possibility has been pointed out that by distilling coal at low temperatures, liquid fuel and other products are obtained, instead of the cracked tars produced by means of the current high temperature practice. It was found that not only was a larger quantity of tar, or oil produced than by high temperature methods, which were known to break up the tars into fixed gas and solid carbon, but that the tars produced during low temperature carbonisation, as well as the solid residue and coke, were of a totally different character to those produced at high temperature.

The characteristics of low temperature, or primary tars, will be dealt with in the next chapter, but, it may be remarked, that although during the last few years, a very considerable amount of work and research has been done on these so called primary tars, still more will be necessary before their intrinsic worth is really known.

Generally speaking, the low temperature, or primary tars are the tars which are first evolved when the coal is distilled and which escape from the distilling apparatus without further material decomposition. In order that this may occur, it has been demonstrated that the carbonisation temperature must not exceed about 500° C. In the gas and coke-oven industry, where temperatures up to 1,000° C. and over are attained, the proportion of volatile products which escape from the apparatus, without cracking, or degradation, is practically negligible, except in the case of vertical retorts.

Results of low and high temperature distillation.

The difference in the results obtained when distilling a coal at low temperature, to those obtained when the coal is distilled at high temperature, are perhaps best exemplified by Table I., which may be taken as average results, for a good English gas coal.

It will at once be clear, why high temperature distillation was adopted for gasworks practice, where the prime factor was gas quantity. Although the solid residual is approximately the same, the high temperature process has clearly cracked some of the primary tars, increasing thereby the gas production.

TABLE I.

Gasworks Process* (Dry Distillation).		Low Temperature Process.†	
Products per ton of coal.	Thermal percentage of original coal.	Products per ton of coal.	Thermal percentage of original coal.
Coke, 14.5 cwts.	66.5%	Coke, 13.9 cwts.	70.1%
Gas, 13,160 cu. ft. of 545 B.Th.U./ft.=71.7 therms	23.8%	Gas, 39.6 therms	13.0%
		Crude Spirit, 1.78 gals.	1.0%
Tar, 9.35 gals.	5.7%	Tar, 18.62 gals.	10.7%
	96.0%		94.8%

The increased quantity of tars or oils produced by low temperature distillation methods, has resulted in low temperature carbonisation being advocated as a means for obtaining home produced liquid fuels, and during and since the war the Government has provided for its investigation by the Fuel Research Board of the Department of Scientific and Industrial Research. In addition, however, to the home production of liquid fuel and other products, which in time of war would be of vital importance, and also in time of peace, a great assistance in redressing our adverse trade balance, the solid fuel resulting from low temperature distillation, differs materially from that obtained by high temperature distillation. Its chief point of difference being its more ready combustibility and its consequent suitability, when sufficiently free from ash, for use in the ordinary English open fire-place.

Coke, as made in gasworks and coke-oven undertakings to-day, is a smokeless fuel, but unfortunately, owing to the difficulty of ignition, its use is mainly restricted to closed stoves. Low temperature coke on the other hand, is easily ignitable, i.e., it can be lighted with paper and sticks in the same way as a coal fire, and burns readily (although, smokeless), with a limited amount of flame. It is specially suitable for use in open fires, owing to its high radiation emission ; and, since it produces flame also, it is a satisfactory fuel for use in most ordinary cooking ranges. Experimental work on the relative efficiency of low temperature coke and other fuels for domestic heating, has been carried out by Fishenden, Bligh and Hodsman, and others, and is described in detail in Part VII.

The reasons for its increased combustibility, or reactivity, over ordinary gasworks coke are still the subject of controversy, and whether this is due to structure, volatile contents, or mineral constituents, and to what extent it is influenced by each of these factors, is by no means determined. The important practical fact remains, that low temperature coke, if made from a sufficiently clean coal is an eminently suitable household fuel.

Not all coals are capable of forming alone such a suitable coke, or smokeless fuel, on carbonisation. Anthracite and the non-coking varieties of coals are useless for this purpose, unless mixed with a proportion of coking coals. This subject, however, is dealt with fully in other sections of this work.‡

There are many coals, nevertheless, which are suitable for low temperature carbonisation, ranging from slightly caking coals, to strongly caking coals, and by blending non-caking with strongly caking coals, so that the plastic constituent of the caking coal is able to impregnate the non-caking coal, the range can be still further widened.

The above limitation refers, of course, to those cases where a lump fuel suitable for domestic consumption is required. Where, however, a pulverised residue can be employed for industrial, or other

*Hardy, T. Some Phases of Modern Practice in Gas Manufacture. Inst. Fuel Tech., 1926.
†Report by Directors of Fuel Research Board on Parker Low Temperature Carbonisation Plant. H.M. Stationery Office, 1924.
‡The Blending of Coals, Part IV.

purposes, the caking properties are not necessary, and all coals having sufficient volatile content to warrant their distillation prior to combustion, can be utilised for this purpose.

From the above, it may be concluded that difficulties are not likely to arise, on the score of there being insufficient quantities of suitable coals, and that there need be no fears as to the possibility of carbonising enough coal, to replace that which is now consumed for domestic purposes in this country (amounting to some forty million tons per annum). The substitution of the latter by an efficient smokeless fuel, opens up an extremely attractive vista, and one which has, unfortunately, carried away many enthusiastic advocates of the process, far beyond the limit warranted by technical progress already made.

Fifty-five million tons of suitable coal, if distilled at low temperatures, should yield (basing the yields on the average results published by the Fuel Research Board and other workers) in the neighbourhood of 1,000 million gallons of primary tars and spirit, and 2,000 million therms in the form of rich gas, together with 40 million tons of low temperature coke. The desirability of achieving such results, if they can be achieved economically, is obvious.

The workers in the field of low temperature carbonisation are legion, and innumerable processes, for this purpose, both practical and impractical, have been proposed.

Classification of processes.

The principal processes may be classified as, external heating processes and internal heating processes, while these again may be sub-divided into static and mechanical, or continuous processes.

As an example of the first class, may be cited the Parker process, where small externally heated cast-iron retorts are charged with coal, and after sufficient time has elapsed to effect its carbonisation, the resulting coke is discharged, while, as an example of the second class, may be cited the Midland Coal Products process, where coal briquettes are charged into a retort and carbonised, by passing hot gases through them.

The former of these processes is a static process, while the latter is a continuous or semi-continuous mechanical process.

Although the numerous processes that have been suggested may be grouped into definite classes, most of them have their own distinctive features, which are of importance in determining the most suitable for a particular set of conditions. A process that was an entire success, under one set of conditions, might be an entire failure under different conditions, and with a different type of coal.

One of the characteristics exhibited by coking coal, is, that, when heated to about 400° C., it becomes plastic, and is, in this state, a bad conductor of heat. In the high temperature carbonisation industry, owing to the considerable temperature difference between the coal and the source of heat, the actual transmission of the heat to the coal is not a difficult matter, in spite of its passing through this stage of low conductivity. But, in low temperature carbonisation, this temperature difference is reduced, and consequently, the transmission of heat to the coal charge presents greater difficulties.

For this reason, it has been proposed by many workers in the field, that, instead of heating the coal charge from an external source, it should be heated internally, *i.e.*, by the passage through the coal of a suitable heating medium.

There are many modifications of this method. For example, hot, inert gas may be passed through the coal in a static retort, the coal remaining quiescent until completely carbonised, or passing slowly down through the retort, the speed of its passage being regulated, so that it is completely carbonised before leaving the retort.

Carbonisation, or distillation, by means of internal heating, need not, of course, be carried out by means of a gaseous medium, as both solid and liquid media may be employed. It has, for instance, been proposed to distil coal by charging it into a molten lead bath, also by passing heated metal balls, or shot, through a chamber along with the coal to be distilled. A disadvantage of the former is, that loss of lead takes place in the process, while the drawback, of both the former and the latter, is the high cost of operating a process essentially suitable for producing a pulverised and, relatively, low value product, adapted only for industrial uses.

Where gaseous heating media are employed, the rich gas evolved by low temperature carbonisation will be mixed with the gas used for heating, and it will be clear that, if an inert gas is employed for this purpose, the rich gas will be degraded or reduced in quality, and the resulting mixture increased in quantity, necessitating larger cooling and condensing plant, etc. The inert gas can, however, be replaced by producer or other combustible gas, in which case, the resulting mixed gas will not be degraded to such an extent. Instead of an inert or low calorific value gas being employed, superheated steam may be used, and this medium offers a number of advantages, two of which may be mentioned.

(*a*) Steam, owing to its specific heat, will carry more heat per pound than other gases.

(*b*) After it leaves the retort it can be condensed and removed from the process in the form of water, so that the distillation gas is not degraded in any way.

A serious disability of employing steam, is that the latent heat of its evaporation cannot be utilised in the process, although methods have been proposed, whereby this disadvantage can be partly removed, by recovering the latent heat of the steam.

Merz and McLellan have proposed to condense the steam, and employ the latent heat of condensation, for evaporating fresh water at a reduced pressure, and then boosting up the pressure again, mechanically.

Another proposal to achieve the same end, *i.e.*, the recovery of the latent heat of the steam, is by employing a mixture of gas and steam as a gaseous heating medium, condensing the steam on leaving the retort, and using the resulting heated water for re-saturating the gas again, before it is superheated and passed back into the retort.

Gaseous heating media have an important advantage when distilling coals at low temperature, in that the primary tars evolved are quickly removed from the apparatus, before they are subjected to a higher temperature, than that which is necessary to evolve them. In this way, they are recovered in an uncracked condition, the gaseous medium acting as a protective covering. It may also be, that partial pressure evaporation takes place in certain processes, due to the presence of the heating gas.

Although, at the present time, only one or two low temperature carbonisation plants are, or have been, operating commercially in this country, a number of different types of plant are in course of construction, or, about to be installed, for producing both household lump fuel and pulverised fuel. Among the former is one on the lines of that developed at the Fuel Research Board's Station, which is to be erected and operated by the Gas Light and Coke Co. at their Richmond Works, and it appears likely that before long definite data will be available, as to the present commercial possibilities of these particular methods of low temperature carbonisation.

Types of coal, and uses for the resulting fuel, vary so enormously that it is quite impossible that any one process will prove the best for all coals and for all purposes, and if only for this reason, the erection of a number of types of plant is to be welcomed.

Low temperature distillation of coal, may also be directly combined with the subsequent gasification of the product and, indeed, plants for the purpose are already in successful commercial operation, but this subject is dealt with fully in another part of this work.

Economic aspect.

In estimating the profitable nature, or otherwise, of the low temperature carbonisation, or distillation process, it is unfortunate that one is not in a position to turn to the industry itself for practical results, but a consideration of the products of low temperature distillation and their present value, will at all events demonstrate that the successful processes in the long run will be those which are cheapest to instal, operate and maintain, for the low temperature distillation of coal is not a gold mine where extravagances, in these directions, can be permitted.

Although, as has been stated, no practical commercial operating results can be quoted so far, results of an analogous industry, viz., the coke-oven industry, may with care be employed as the basis of an estimate, as to the commercial possibilities of the low temperature distillation process.

A modern coke-oven plant may be erected at a total cost of, approximately, 25s., and a modern gasworks plant at a cost of 30s. per ton of coal carbonised, per annum. The operating costs of the coke-

oven plant, that is, the total cost of carbonising and recovery of by-products, would be in the neighbourhood of 5s. per ton. Taking interest and amortisation at 15 per cent., this will amount to 3s. 9d. per ton, or a total cost of 8s. 9d. per ton of coal carbonised. If the capital charges are based upon the gas works figure, the total cost will be 9s. 6d. per ton carbonised, and this expense would have to be met by the enhanced value of the products of carbonisation.

Taking first the cost of a clean suitable slack coal, procurable at, say, 15s. per ton, the products obtainable may be taken as follows :—

Coke and breeze, say	14.5 cwts.
Primary tar or oil, say	16 galls.
Motor spirit scrubbed from the gas and distilled from the primary tar, say	2 galls.
Gas, say	33 therms.

These products may be obtained from many coals, although the quantities will obviously vary, depending upon the type of coal employed. The above may, however, be taken as typical figures from suitable coals. When we come to the evaluation of these products, the problem is much more difficult. The value of the coke, or smokeless fuel, will depend upon many factors, including the value of an equivalent alternative fuel, the distance from a market, the realisation of its intrinsic value by the public, etc., but, for the purpose of a provisional calculation, the value of 25s. per ton may arbitrarily be taken.

The tar is equally difficult to evaluate. If based on fuel values, it is, probably, only worth 3d. to 4d. a gallon, but, as our knowledge of the low temperature tars increases, it is fairly safe to assume, that the money value of the tar itself will increase. The writer is aware of a semi-low temperature tar being sold, to-day, under 12 months contract, for 6d. per gallon, f.o.r. the maker's works.

The tar may be fractionated and purified, and it is claimed that the following products can be obtained :—

Light burning oil; Diesel or fuel oil; light lubricating oil; heavy lubricating oil; paraffin wax; phenols and cresols; pitch coke; and unsaturated compounds.

The lubricating oils obtained by Nielsen are, according to him, extraordinarily stable at high temperature. The phenols and cresols possess exceptionally high germicidal properties, from 15 to 16 times that of pure carbolic acid. In addition to these uses, the phenols also have a considerable outlet in the Bakerlite and allied industries.

Other investigators have either failed to detect similar lubricating fractions among the products of low temperature tars, or have not looked for them, and it is possible that some of the products, found by Nielsen, may be synthetic products of the reaction between carbon monoxide and hydrogen, in the presence of a suitable catalyst (similar to those produced by Fischer at atmospheric pressure).

The motor spirit we may take at 9d. per gallon. The sulphate of ammonia, owing to the small quantity that could be recovered, and the present depressed market value, has been ignored.

The value of the gas will, again, depend upon the possibility of distributing it in a similar manner to that distributed by gasworks. In that event it is, probably, worth 4d. per therm, as this is the approximate cost of gas "into the holder," for most gas undertakings. If, however, it has to be used as best it can, in place of solid fuel, it is, probably, only worth 1d. per therm, but, in view of the possibility of obtaining very much more for it, 2d. per therm may be taken as a fair average figure.

Table II. gives a summary of the products, and the average values we have, provisionally, decided upon.

Table II.—Products per Ton of Coal.

			s.	d.
Coke	14.5 cwts.	at 25s. per ton	18	3
Gas	33 therms	at 2d. per therm	5	6
Tar	16 gallons	at 4d. per gallon	5	4
Spirit	2 gallons	at 9d. per gallon	1	6
			30	7

We have seen that, from this amount, has to be deducted, approximately, 9s. per ton of coal carbonised, leaving 21s. 7d. to pay for the ton of coal employed. If, therefore, the plant be installed, where a suitable fine coal can be obtained at a reasonably low figure, and where the above values can be obtained for the products, the operation of such an installation should be a profitable one.

In the case of the pre-carbonisation of an industrial fuel, the situation is different.

Assuming the same products are realised, per ton of coal carbonised, the values will, obviously, be changed.

The value of the coke will have to be commensurate with the value of an alternative fuel, bearing in mind the advantages, and possible greater efficiency, of low temperature coke as an industrial fuel, mentioned later.

As industrial plants will, in many if not in most cases, be most favourably installed where the low temperature coke is required (an important advantage of this being the fact that it can be fed hot to the furnaces without loss of the sensible heat remaining in the coke after carbonisation) the gas may have to be consumed there and then as fuel, owing to no alternative outlet being available, consequently, 2d. per therm may be too high an evaluation for the gas.

Without taking into account these differences in value, except that of the solid fuel, Table III. gives a summary of the average values of the products, resulting from the carbonisation of an industrial fuel.

TABLE III.—PRODUCTS PER TON OF COAL.

			s.	d.
Coke	14.5 cwts.	at 15s. per ton	10	10½
Tar	16 gallons	at 4d. per gallon	5	4
Gas	33 therms	at 2d. per therm	5	6
Spirit	2 gallons	at 9d. per gallon	1	6
			23	2½

It will be seen, therefore, that there is a much smaller balance in this case, to pay for the cost of operating the process, the cost of the original fuel and for providing a profit.

The original coal, will, of course, be a cheaper material than that necessary for manufacturing a household smokeless fuel, the costs of operation, too, will probably be lower, owing to the nature or grade of the resultant fuel being a less important factor, and to the fact that the pre-carbonisation will be carried on as part of an undertaking which would, in any case, have all standing charges, management, etc., to bear.

Given similar conditions the low temperature carbonisation of slack coal, and the production therefrom of a lump, smokeless, domestic fuel, appears to offer the most promising prospect. The carbonisation of coal for industrial purposes is handicapped, in so far as the value of the resulting carbonised product is dependent only upon its calorific value, and not upon its grade, as is the case of domestic fuel. This is not to say that low temperature carbonisation of an industrial coal will not be justified, since, due to the very fact that its physical condition and grade is a matter of secondary importance, it will, probably, admit of being carbonised much more cheaply than where its condition and grade is of importance. For example, one process which has been suggested, and is now being tried on a large scale, consists in carbonising the coal in pulverised form by permitting it to fall through towers, up which hot gases are passed. The resulting coke is, also, in a pulverised form. The simplicity of this process is most attractive, and if a large throughput, per carbonising unit, is achieved, and the efficient separation of the fine coal and coke dust from the gas can be attained, so that the resulting tars are not thereby contaminated, it should be possible to construct plants and to carbonise coal very cheaply by this means.

Although it has been said that the value of the carbonised product for industrial purposes is wholly dependent upon its calorific value, it should not be overlooked that this calorific value is influenced by the fact that low temperature coke for steam raising, and other industrial purposes, is more efficient than bituminous coal, particularly at low rates of combustion.

This increased efficiency, is mainly due to the fact that the fuel can be consumed with the minimum excess of air, and, furthermore, owing to the more reactive nature of the coke fuel, the evolution of radiant heat is higher than with coal.

Another factor, also, that should be credited to the coke when taking into account its calorific value, is that, after carbonisation, if supplied direct to the furnaces, it is dry, whereas the coal itself, before carbonisation, would inevitably contain a certain percentage of moisture, which would have to be evaporated at the cost of a proportion of its calorific value. Furthermore, when supplied directly to furnaces, the coke retains an appreciable amount of sensible heat which will, naturally, increase its calorific effect.

Still another advantage possessed by low temperature coke, is in its use as a gas producer fuel. Owing again to its reactive nature, existing producers can be operated at a higher throughput than with other fuels, while with coals having ash of low fusing point their pre-carbonisation at low temperatures can result in a fuel so reactive that it can be gasified efficiently (without, that is, an excessive production of carbon dioxide) at a temperature below the melting point of the ash, so obviating the clinkering troubles which would occur with the gasification of the raw coal, or a coke produced at high temperatures.

For industrial purposes, the development of pulverised coal firing is making rapid strides, and, there is no reason whatsoever why this should not go hand in hand with the development of pulverised coke firing. Indeed, certain advantages are claimed for pulverised low temperature coke over pulverised coal. For instance :—

(1) Owing to the volatile matter having been mainly removed, and the fuel rendered more reactive, the length of flame is reduced and consequently the size of combustion chambers can be reduced.

(2) The storage and conveyance of pulverised coke is not subject to the risk of spontaneous combustion, as is that of pulverised coal, and the time indeed may come when not only locomotives and steamships will be able to consume pulverised coke, but fuel in this form will be delivered in tank wagons to industrial and possibly to domestic consumers, as liquid fuel can be delivered to-day.

Up to the present time, the gas industry has developed on the lines of installing the gas-producing plant where a demand exists for the gas. In general, where coal supplies are more or less widely distributed, or cheap water transport is available, as in this country, this policy has been justified. Nevertheless, the time has probably arrived when the policy should be reconsidered, in the light of recent developments of modern knowledge.

In Germany, the tendency is to concentrate the carbonising industry in the coal districts in large units of the coke-oven type, and to pipe the gas, at high pressure, to the point of consumption. This is done, even to-day, over hundreds of kilometres, while serious proposals are now on foot for distributing gas generated in the Ruhr district, as far as Berlin, and linking up the coal districts by means of a grid of high pressure gas mains, in a similar manner to the proposed electrical grid now being formulated in this country.

Considerable opposition is, of course, being put forward to these proposals in Germany by vested interests, and, at this date, it is impossible to say whether, or how far, the proposed scheme will be carried through. So far as the actual transmission of gas over long distances, however, is concerned, there is no insuperable difficulty entailed, and the situation of the gas-producing plant in the midst of the residential and urban districts is no longer necessary, and is, indeed, to be deprecated.

The low temperature carbonisation industry, therefore, if established in the coal districts, or near cheap coal supplies, need not assume that, owing to there being insufficient local demand for its gas, it will possess only a fuel value based upon local solid fuel, as gas can, to-day, be transmitted economically, at high pressure, over considerable distances. How far this will be commercially practicable, remains to be seen.

Visualising the possibility of the pre-carbonisation of a large proportion of the coal consumed in this country, though interesting and also useful, so far as the bearing it would have upon the final results of such a consummation, is not of vital importance in the early days of the industry, since, during the initial period, the quantity of coal carbonised and the products manufactured, will not be such as to affect, materially, the market value of the products. Indeed, the law of supply and demand would, immediately, check further developments should such a situation arise.

Chapter 2.

LOW-TEMPERATURE TARS, AND THEIR CHARACTERISTICS.

By F. S. Sinnatt, M.B.E., M.Sc., F.I.C.

The economic prospects of every process of low-temperature carbonisation depends largely, if not essentially, upon the amount the tars will realise when sold under normal commercial conditions. Statements as to the value of the tars have, up to the present, been based upon experiments carried out upon a small scale since, with few exceptions, little opportunity has existed of treating sufficient quantities of the tars, their derivatives and fractions, to admit of trials on a commercial scale. When tar and oil distillers have obtained the fractions from the tar, and compared them with ordinary coal-tar products, and both groups of materials have been disposed of in normal markets, it will be possible to state, accurately, the value of low-temperature tar. Such tars, undoubtedly, possess special characteristics, when compared with high-temperature tars, but whether these will increase their commercial value is still uncertain. It must be recalled that the tar produced in vertical retorts, which differs in properties from that obtained from horizontal retorts, has not proved of greater commercial value than the horizontal tar. Certain authorities have expressed the view that vertical retort tar resembles low-temperature tar, in some respects.

The cost of refining tar is not inconsiderable, and this must be taken into account in assessing the commercial value of the special fractions for which treatment with reagents and accurate fractionation have been required. The general trend of the investigations of low-temperature tar suggests that the commercial value will not be greater than the average value of crude fuel oil, and high-temperature tar. The following tables contain the imports of petroleum products and the amount of coaltar produced in the country, together with the value of the fractions, or tars.

Table I.—Petroleum Imports for 1925-1926.

	1925.		Pence per	1926.		Pence per
	Galls.	£	gall.	Galls.	£	gall.
Illuminating Oil	141,649,425	2,927,588	4.25	201,950,966	4,759,955	5.65
Motor Spirit	404,834,226	16,826,010	9.97	562,176,619	21,567,931	9.21
Lubricating Oil	84,361,784	4,717,406	13.42	91,810,250	4,670,386	12.20
Gas Oil	72,652,528	1,276,220	4.21	117,042,798	2,068,721	4.24
Fuel Oil	334,489,850	4,654,861	3.33	398,443,393	5,381,077	3.21
Crude Oil	569,082,169	8,864,530	3.73	538,239,606	8,204,011	0.91

Table II.—Coal Tar Distilled in Great Britain during the Years 1915 to 1925.

Year.	No. of works.	Tar distilled, tons. Gasworks, coke ovens.	Other works.	Pitch produced. Gasworks, coke ovens.	Other works.
1915	296	1,446,900	313,511	740,208	153,199
1916	365	1,560,064	264,837	785,930	158,964
1917	410	1,669,178	246,155	788,044	144,927
1918	425	1,652,287	251,874	787,637	138,027
1919	426	1,563,876	205,442	696,858	119,396
1920	425	1,592,081	221,339	739,556	121,248
1921	Not available.	1,129,425	72,436	425,360	39,290
1922	—	1,314,995	44,170	490,573	23,663
1923	England, Wales and Scotland.	1,682,168		677,362	
1924	„	1,813,728		625,222	
1925	„	1,679,348	10,145	515,506	4,312

In 1922 and subsequent years the figures for the Irish Free State are not included.

The plants for the distillation of tar are frequently part of the coal-gas works, or are associated with coke ovens.

Considerable variations in the price obtained for the tar from the low-temperature carbonisation of coal may be expected in different localities, and the price received for ordinary coal tar by gasworks forms a basis on which to judge the order of the fluctuations possible. Table III. shows the price in pence per gallon quoted by a number of gas companies and corporations throughout the country :—

TABLE III.—VARIATIONS IN PRICE OF GAS TAR IN GREAT BRITAIN (1919 TO 1924).

	Values in pence per gallon.					
Companies.	1919.	1920.	1921.	1922.	1923.	1924.
Gas, Light and Coke	3.91	8.11	3.25	3.72	6.40	4.57
Commercial	4.72	9.99	4.40	4.32	6.98	3.61
South Metropolitan..	3.72	10.77	5.10	4.12	7.03	3.36
Suburban—						
Average	4.13	8.15	5.19	4.33	6.49	3.85
Highest	4.72	9.80	6.34	4.92	7.62	4.93
Lowest	2.21	4.95	3.36	2.96	5.13	2.90
Provincial—						
Average of 9	2.98	6.18	5.23	4.39	6.00	4.65
Highest	4.38	7.85	10.12	7.25	8.10	6.98
Lowest	2.03	3.75	3.02	3.11	4.35	3.00
Corporations—						
Average of 11	2.89	4.33	6.73	4.06	4.73	5.60
Highest	4.99	7.83	11.16	7.14	6.33	7.23
Lowest	1.77	2.74	4.03	2.69	3.60	4.35

The price obtained for coal tar is different at each gasworks, and the difference between the highest and lowest figures quoted in the above table emphasises the variations which have occurred in the particular years shown. Thus in 1921, one gas company received 10.12d. per gall., whilst another obtained only 3.02d. In the year 1924, the highest price obtained was 6.98d., and the lowest 2.9d. per gall. The reason for these fluctuations in the price of an important by-product, such as tar, is conceivably due to the fact that, while normally sold to the best advantage, it may frequently become expedient to dispose of it cheaply in order that the production of the vital product, coal gas, may not be interrupted. The variations in revenue created, would, of course, be taken up by adjustments in the price of the vital product (gas).

The above fact is of importance in considering the operation of a low-temperature carbonisation plant under private ownership. The vital commercial product of a gas works is town's gas, the price of which may be altered to meet the fluctuations in the prices of the coal used, and the by-products obtained. Gas works may, therefore, be in a position in any particular locality to offer tar at a price which would be such as to undermine the economic prospects of a low-temperature carbonisation process situated in that area.

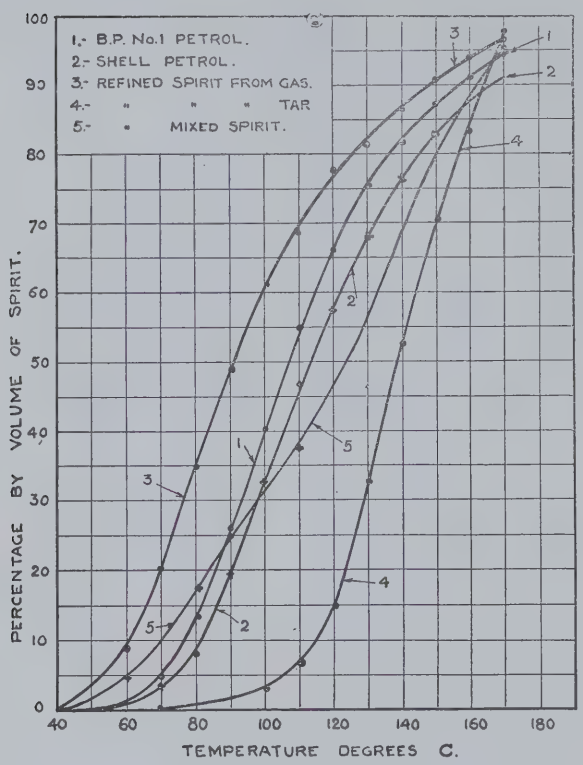
The following is a brief summary of the various ways in which low-temperature tar, and the products derived from it may be utilised in commerce :—

(1) Liquid fuels:
  (a) Light motor fuels.
  (b) Fuels for Diesel engines and other oil engines.
  (c) Fuels oils for steam raising.
  (d) Oil for oil-gas manufacture and for the production of carburetted water gas.

(2) Source of coal-tar products.
  (a) Phenol, cresols, creosote, xylenols, higher phenols.
  (b) Hydrocarbon distillates, suitable for solvents, dry cleaning, etc.
  (c) Tars and tar preparations.
  (d) Pitch possessing special characteristics.

(e) Source of valuable products, such as beta methyl anthracene, high-boiling phenols, paraffin wax.

(3) Source of lubricating oil bases. The question of the production of really high-class lubricating is more speculative. Practically any type of oil may be used as lubricant for certain purposes and "heavy oil," a fraction from high-temperature tar, has been largely used as a lubricant. Since low-temperature tar contains practically no naphthalene it should be superior to ordinary coal tar as a base for lubricating oils. Lunge considers that heavy paraffin and petroleum oils and rosin oil are far superior lubricants and are nowadays cheap enough to make the employment of coal-tar oils superfluous.



Distillation Ranges of refined spirit from low-temperature gas and tar in comparison with that of petrol.

The composition of the tar produced during the destructive distillation of coal, at so-called low temperatures, which, for the purposes of this chapter, will be assumed to be below 700° C., depends not only upon the temperature and upon the rate at which the heat penetrates the mass of coal, but also upon the system of carbonisation. A great many workers are engaged upon the problem, and considerable differences of opinion exists as to the exact part played by each of the above factors. One point which has emerged recently, indicates that tar is evolved from coal at, relatively, low temperatures, especially if the coal is subjected to a stream of inert gas. Recent work carried out at the Fuel Research Station, as a result of a discussion with Mr. H. Nielsen, shows that coal commences to decompose at the following temperatures.

TABLE IV.—INITIAL DECOMPOSITION TEMPERATURES OF SIX TYPES OF COAL IN A STREAM OF NITROGEN.

	Initial appearance deg. C.	Colour of oil	Remarks
Peat	180	Brown ..	.. Fumes appeared at 170° C.
Lignite	235	Brown-yellow	.. Fumes appeared at 205° C.
Bit. str. caking .. .. ("Mitchell Main")	215	Yellowish ..	.. Fumes appeared at 210° C.
Bit. med. caking .. .. ("Dalton Main")	230	Yellowish ..	.. At 200° C. acid fumes appeared, containing hydrogen sulphide and acetaldehyde. Oil fumes appeared at 210° C.
Bit. non-caking .. .. ("Ellistown Main")	245	Yellowish ..	.. Fumes appeared at 230° C. acid in character.
Anthracite	—	—	No oils appeared up to 550° C. Ammonia evolved in quantity at about 450° C.

King and Willgress—Fuel Research Board Technical Paper No. 16.

The literature of low-temperature tar is now extensive, and it is impossible, within the space available, to trace the investigations which have been carried out on the subject. The history and literature has been exhaustively examined by E. Parrish (Fuel 1926.5.436), and it is proposed to deal with only the salient researches.

Burgess and Wheeler (Trans. Chem. Soc., 1910.97.1925), experimenting in a platinum retort, with two grams of coal, found that the Silkstone coal (coal A) the maximum yield of tar was obtained at about 750° C., whilst with coal from Abertillery (South Wales) coal B, maxima were found at 600° and 800° C.

TABLE V.

Temperature of carbonisation, deg. C.	Percentage of tarry matter on the ash-free dry coal.	
	Coal A.	Coal B.
450	4.3	—
500	9.0	7.0
600	13.6	10.0
700	14.0	7.3
750	16.2	—
800	13.5	10.5
900	12.2	9.6

Working with units of about 100 lbs. in a plant in which the coal was externally heated, the following results were obtained (King, Linnell and the author, J.S.C.I., 1926.47.385) :—

TABLE VI.

Temperature of carbonisation, deg C.	Yield of tar per cent. of coal.	Yield of tar gallons per ton.
400	3.9	9.1
450	5.6	12.8
599	7.0	16.0
550	8.0	17.6
600	7.6	16.4
650	6.9	14.3
700	6.2	12.9

The yield of tar depends upon the conditions prevailing in the coal, and the type of plant used. The following yields of tar have been obtained in the tests of commercial plants, carried out by the Department of Scientific and Industrial Research :—

	Yield of tar, galls. per ton.
Parker Low-temperature Carbonisation Plant (Coal: Dalton Main) ..	18.6
Midland Coal Products, Ltd. (Coal: Nottingham Top Hard)	21
Fusion Rotary Retort (Cannel)	50.2
Freeman Multiple Retort (Coal: Kirkby Top Hard)	20

The effect of the temperature, and the method of carbonisation upon the constitution of the tar, is of importance, and Nielsen has expressed the view that when tar is formed it must be swept from the coal and should not be exposed to any higher temperature than that of the gases used to heat the coal. In these circumstances, he states, the tar differs in properties from that formed when the coal is externally heated. Tars made by the latter method are stated to have undergone thermal decomposition after formation. Tars, which have not been exposed to cracking, have been termed " primary " tars, and Fischer (" The Conversion of Coal into Oil," page 30) states that primary oils must satisfy the following tests :—(a) The specific gravity of the fraction, boiling between 200 and 300° C., of the portion of tar soluble in light petroleum (B.P. 30-65° C.), should not exceed 0.95 : (b) this fraction should be completely soluble in ether or light petroleum ; (c) the specific gravity of the residue, from the above, should not be more than 1.0 at 50° C.; (d) naphthalene should not be present.

The values quoted in Table VII. indicate the influence of the temperature of carbonisation upon the constitution of the tars. The tars were first distilled and then separated into the main constituents.*

TABLE VII.—CONSTITUTION OF TAR OILS 400° TO 700°.

Percentages by weight of oil.

	Temperature of carbonisation, deg. C.						
	400°	450°	500°	550°	600°	650°	700°
Phenols	24.55	29.12	29.20	29.31	32.97	35.45	35.98
Bases	1.62	2.06	2.35	2.66	3.00	3.15	2.54
Neutral oil	73.80	66.98	66.05	67.77	62.87	60.11	60.03
Unsaturated compounds ..	44.0	46.1	45.4	47.3	48.4	50.9	52.2
Saturated oils	29.8	20.9	22.9	18.5	13.4	8.6	6.2
Tar dry—							
Sp. gr. at 15°	0.958	0.980	0.986	1.015	1.039	1.078	1.080
Galls. per ton of coal ..	9.1	12.8	16.0	17.6	16.4	14.3	12.9

Although the above results were obtained by the examination of only one seam of coal, the following observations are permissible. The phenols gradually increase with rise of temperature; the neutral oil diminishes with rise of temperature, while the saturated oils rapidly fall until at 700° C. only 6.2 per cent. are present. These facts are of some moment, since the properties of the neutral oils are of considerable practical importance.

It may be assumed that low-temperature tar consists of hydrocarbons, phenolic substances, bases and pitch.

The hydrocarbons, or neutral oils.

These have not been completely identified, or accurately determined, but it would appear that the tar contains members of the following homologous series of hydrocarbons:—The methane, or paraffin series, naphthenes, olefines, unsaturated polymethylenes, substituted naphthalenes, and anthracenes. The constitution of the neutral oils is of considerable interest, since they have been found to possess valuable properties as motor fuels.

It is well known that no methods are available for the accurate determination of the above compounds, in the presence of one another, and the values, given below, are the approximate percentages found in one specimen of oil, from an externally heated system of carbonisation.†

TABLE VIII.	Percentage by weight of the hydrocarbon or neutral oil.
Paraffins and naphthenes	17.6
Unsaturated aliphatic compounds	30.6
Compounds combining with picric acid, naphthalenes and anthracenes, etc. ..	27.2
Unsaturated polymethylenes and aromatic compounds, not forming picrates ..	24.6

The neutral oils contain sulphur and nitrogen and 1.3 per cent. of the former was found in a neutral oil separated from a specimen of tar which contained 1.7 per cent. Parrish and Rowe (J.C.S.I. 1926 45 99T) found 1.5 per cent. of sulphur in the neutral oil from a tar containing 1.3 per cent.

An important addition may be made to the volume of tar recovered by ordinary condensation by washing or scrubbing the gas produced during the carbonisation. The amount of spirit recovered in one series of experiments was 1.5 gallons per ton of dry coal. When this was refined, the yield was 1.39 gallons of spirit having a specific gravity of 0.72. The spirit was lighter than ordinary motor spirit, and it may be mixed with the heavier spirit obtained by the distillation of the tar. The spirit from the tar

*King, Linnell and the author, *loc. cit.* †Brittain, Rowe and Sinnatt, *Fuel*, 1925.4.300.

amounts to about 1.2 to 1.5 gallons. The amount of light motor fuel is about 2.6 gallons per ton. The distillation range of the mixed spirit resembles that of good petroleum spirit. Comparative graphs of the distillation ranges of various light motor fuels are given in the diagram (page 422). Certain investigators have found small amounts of the simple aromatic hydrocarbons in low-temperature tar, while others have been unable to detect these compounds.

The phenolic compounds.

These have been investigated by Edwards (J.S.C.I. 1924.43.143), who was one of the first to recognise the unstable character of low-temperature tar, and to adopt methods to prevent decomposition during the investigation. Edwards was able to resolve the phenols into two main groups, the first includes phenol and its homologues, dihydric compounds and similar bodies, and the second group consists of bodies of unknown composition designated "Rhetinols." The rhetinols form about 9 to 12 per cent. of the tar, and possess some of the characteristics of the phenols; on distillation, they boil with decomposition at about 300° C., yielding homologues of phenol, water, and aromatic hydrocarbons. Edwards states that, the rhetinols appear to be the intermediate stage between ulmin-like compounds in the coal, and the homologues of phenol. The table which follows, contains the proportion of the phenolic substances found in two specimens of tar examined by Brittain, Rowe and Sinnatt, and Parrish and Rowe.

TABLE IX.

Per cent. by weight of the tar.

	Brittain, Rowe, Sinnatt.	Parrish and Rowe.
Phenol	0.2	0.7
Ortho cresol	2.3	—
Meta cresol	2.9	6.8
Para cresol	—	—
Xylenols	4.7	6.1
Catechol and higher phenols	8.7	4.7
Resins (rhetinols)	10.9	15.5

The technical applications of these compounds have not been fully realised, and the higher phenols and rhetinols require more detailed study.

Nitrogen compounds.

The amount of ammonia formed, during the carbonisation of coal at low temperatures, is smaller than is produced by high-temperature carbonisation. The proportions of nitrogen compounds in the tar, varies from 2 to 4 per cent., while a quantity is removed by the water used in scrubbing the gas. In one case, the bases present in the aqueous liquor were equivalent to about one-seventh of the ammonia. Little accurate information is available upon the constitution of the bases, and their chief interest, from a technical point of view, lies in their influence upon the properties of the hydrocarbons and the phenols. It is stated that these compounds must be eliminated from any fractions which might be used as high-class lubricants.

The bases form dark coloured viscous oils, soluble in most organic solvents, and thus they readily dissolve in the hydrocarbon fractions of the tar. Although one investigator has detected primary amines in low-temperature tar, it is generally considered that only secondary and tertiary are present. The following are among the more important compounds: — di and tri-ethylamine, pyridine, 2 methyl pyridine, 2.3 dimethyl pyridine, trimethyl pyridine, quinoline, methyl quinoline, hydroquinoline.

Sulphur compounds.

These compounds are of great interest, owing to their influence upon the hydrocarbons and phenols. No comprehensive study of the organic sulphur compounds in low-temperature tar has been published, and the constitution of the compounds in the hydrocarbon fractions and phenols is unknown. A proportion of the compounds are, probably, members of the aromatic series.

Sulphur is found in the chief constituents of tars, as will be seen from the following values.

TABLE X.—SULPHUR IN CONSTITUENTS OF LOW-TEMPERATURE TAR.

Constituents of tar.	Sulphur % by weight. Tar A %	Tar B %	Parrish and Rowe.
1. Original crude tar	1.49	1.73	1.35
2. Hydrocarbons and neutral oil	1.74	1.30	1.53
3. Phenols and hydroxy compounds	0.77	0.951	0.73
4. Bases	0.99	1.40	0.77
5. Solid A	—	5.765	1.19
6. Solid B	3.82	4.43	

Utilisation of low-temperature tar.

In the early stages of the utilisation of low-temperature tar, the method of treatment for the recovery of coal tar products will, no doubt, be similar to that now used for ordinary coal tar, but, as the amount to be treated increases, new methods will be introduced more suited to the characteristics of the tar. Some work has been carried out upon the "cracking" of the tars, with the object of increasing the yield of light motor fuel, and this principle is a promising one, since the value of light fuels is, as a rule, about three times that of crude fuel oil (see Table I.). Lubricating oil is, generally, about four times the price of fuel oil.

If the process of low-temperature carbonisation is developed to such an extent that a large proportion of the coal now used raw in domestic grades is treated, the amount of tar obtained will be such that a large part will have to be utilised as fuel oil. Fuel oils are valued on a basis of their calorific value, but other important characteristics are the setting point, viscosity, flash point, sludging value, sulphur content, and miscibility with other oils. Crude low-temperature tar, and certain fractions obtained by ordinary distillation, contain up to 30 per cent. of phenolic bodies, and their calorific value is lower than oils derived from petroleum. Low-temperature tar has a calorific value of 15,500 to 16,500 B.Th.U. per lb., while crude petroleum varies from 18,600 to 19,600 B.Th.U., per lb. It follows that, crude low-temperature tar and its fractions, unless the phenolic bodies are eliminated, will realise less on the fuel market than corresponding oils from petroleum. Low-temperature tars are not miscible in all proportions, with petroleum oils, and this must limit their application until sufficient is available to satisfy foreign depots from home sources. If low-temperature tar and petroleum are mixed together, a precipitation occurs, and the deposit varies with the type of tar and petroleum, from an oil-like sludge to a material resembling pitch. The amount of the deposit, in extreme cases, may be 50 per cent. of the tar present. It will be recognised that the formation of such deposits in the tanks and pipe lines of sea-going vessels would be a source of considerable trouble and danger. The following is abstracted from a paper by King, Linnell and the author (loc. cit.).

The solubility of the filtered tar, from externally heated retorts, in various common organic solvents has been determined, and the miscibility of the soluble portion with petroleum fuel oils examined. In no case, was miscibility complete until 35 per cent. of the tar had been precipitated and separated. This quantity is 8 per cent. greater than the pitch produced by distillation, and this fact rules out one of the advantages of a separation method. If the yields of miscible oil were identical, it is doubtful whether the cost of a separation process would not be greater than that of a distillation method. It is apparent, therefore, that the chief advantages to be claimed for a method involving separation with solvents, would lie in the enhanced commercial value of the products. The following is a brief summary of the behaviour of the tar, when two volumes of solvent were mixed with one volume of the tar:—

Methyl alcohol.—A small quantity of soft pitch is precipitated and about one-third of the tar passes into solution.

Ethyl alcohol.—The pitch precipitated is harder, and contains solid paraffins which may be recovered.

Ether.—About 1 per cent. of a black solid is precipitated.

Carbon tetrachloride.—About 7 per cent. of a brown amorphous solid is precipitated.

Pyridine, chloroform, penta- and tetra-chloroethane.—The tar is almost completely dissolved.

Light petroleum (b.p. below 40° C.):—50 per cent. of a viscid oil separates, whilst with petroleum fractions, boiling between 80-100° C. and 120-140° C., 35 per cent. of a pitch-like residue is produced.

Low-temperature tar spirit (0-150° C.):—10 per cent. of a hard pitch is formed.

An examination of the tar, by the ordinary distillation method, and by a separation method involving precipitation with ether, light petroleum, and dilute acid gave the results in Table II.

TABLE XI.—COMPARISON OF DISTILLATION AND SOLUTION METHODS OF TAR TREATMENT.

	Percentages by weight of tar.			
	Solution method.		Distillation method.	
Phenols	26.1		23.3	
Phenol		0.3		0.3
Soluble in light petroleum		19.6		19.7
Insoluble in light petroleum		6.5		3.5
Bases	2.7		2.5	
Unsaturated	6.6		8.1	
Refined oils	41.6		33.5	
Volatile to 360°		33.3		31.4
Insoluble in methyl sulphate		19.4		15.5
After treatment with conc. sulphuric acid		8.2		7.0
Solid paraffin, m.p. 62°		0.1		0.1
Pitch			32.3	
Precipitate from light petroleum	13.9			
Ether	0.9			
Dilute acid	8.1			
From distillation of refined oil		8.2		2.1
Total pitch		(31.1)		(24.4)
	99.9		99.7	

Certain differences in the yields are at once apparent. The refined oil is higher by the solvent method, but, on distillation, it is found that the increase is represented, chiefly, by an increased proportion which is not volatile at 360° C. The distillate has a similar distillation range, and contains a similar amount of saturated compounds, to the corresponding product obtained by distillation. It seems not improbable that, if the percentages of the following are combined:—(a) the precipitates formed by treating the tar with ether and light petroleum, (b) the material produced by the action of sulphur acid, (c) the residue obtained when the refined oil is distilled up to a temperature of 360° C.—the amount will be, roughly, equivalent to the pitch formed by the ordinary distillation of the tar.

The yield of phenols from the oil obtained by treatment with solvents was higher than from the distilled oil, but the amounts soluble in light petroleum were the same in each case. As the insoluble phenols boil over 300° C., it is probable that the difference is represented by the small amount left in the distillation pitch. The nature of the phenols is also similar in both cases.

The quantities of the bases separated from each tar, and the proportions of primary, secondary, and tertiary bases, are similar by both methods of treatment. These comparisons suggest that the two methods of separation have yielded, so far as the oils are concerned, products which do not differ greatly, and it is, therefore, doubtful whether any advantage can be claimed for the solvent method of separation. It has already been stated that no advantage can be claimed on account of reduction of pitch formation.

PART VI.—THE GASIFICATION OF COAL.

INTRODUCTION.

By Arthur H. Lymn, M.I.Chem.E.

As this book relates to Britain's fuel problems one is naturally led to ask the question what is Britain's fuel problem generally. The answer presumably is "the provision for the community of the maximum benefit obtainable from the potential heat value contained in the fuel."

Applying this answer to the gasification of coal, the subject may be looked upon from two points of view.

(1) The production and delivery of the maximum percentage of the heat units from the fuel for use in processes manufacturing products of general utility.

(2) The direct distribution to the consuming public of the maximum percentage of the heat units emanating from the coal at the cheapest possible price.

(1) Under this head will fall all the types of apparatus which may be classed as gas producers, and which are used to a very wide extent throughout all branches of industry involving the heating of furnaces or the production of power. In the amount of space available in a book of such wide scope it is impossible, out of such ample material, to do more than make a limited selection for detailed consideration.

The fuels available in this country for use in gas producers are ordinary bituminous coal, coke, anthracite, and in smaller quantities lignite, shale, peat and wood. It is not overlooked that in Continental countries the last four of these are utilised on a very large scale, but they cannot be considered as part of the fuel problem in reference to this country.

We are, therefore, left with bituminous coal, coke and anthracite. Coke is only used at present on a large scale in those cases (*e.g.*, gas works) where it is actually produced and where the high grade gas is delivered to the public. Generally speaking, in these cases the coke is not gasified with adequate efficiency, and although the most eminent gas undertakings are now devoting considerable attention to the efficiency of their gas producers, there still remains a great deal to be done.

It is the general custom in gas works to build the retort benches with self-contained gas producers, which can only consume with inadequate efficiency a good saleable grade of coke. The direction in which the use of gas producers can be developed for these purposes is to instal separate gas producer plant of the mechanical type which can deal with the coke screenings or other poor grades, thus setting free for the market the good grade of coke. This involves a somewhat higher capital outlay, but in Continental countries, notably Germany, it is held to be decidedly profitable, and installations are now being erected in this country which it is hoped will demonstrate their fuel-economic advantages. A brief outline of such an installation is given in a later chapter.

This naturally leads to the consideration of the somewhat analagous application of gas producers to coke-oven plant.

Coke ovens, whether regenerative or otherwise (as is well known) are generally fired by means of the gas which they produce in manufacturing the coke for blast furnace and other metallurgical purposes.

It is clear, however, that in those parts of the country where coke-oven gas (the thermal value of which is equal to that of town gas) can be supplied to towns within moderate distance of the coke ovens there would be a decided local or national economy if these ovens were fired by gas producers (using poor grade coke), thus setting free the whole of the coke-oven gas for distribution to local communities.

A certain amount has already been done in this direction, *e.g.*, the towns of Sheffield, Newcastle and Middlesbrough are supplied with large quantities of coke-oven gas, which in the near future will be still further augmented. Nevertheless, very much more can be done in this direction, and we might take

our cue from Germany, where in the Ruhr district practically the whole of the towns are supplied with coke-oven gas from the collieries in that area. These are, however, local considerations to be dealt with according to each country's circumstances, and the point is merely indicated here as one of the problems which the gas producer will help to solve.

Another fuel available in this country in considerable quantities is anthracite, a large amount of which, also, is exported. That which is consumed in this country is mostly used for domestic purposes and small gas producers of the suction type. These latter also utilise coke as an alternative, but the total fuel consumption, both anthracite and coke, in these plants is only a relatively small percentage of that which is consumed in the large gas producer plants, and the suction gas producer cannot therefore be considered as playing any considerable part in the solution of Britain's fuel problems. It is, therefore, not proposed to devote any further space to it.

Hence we are left with ordinary bituminous coal, which is the fuel of by far the greatest importance in Great Britain. The following chapters are written by their respective authors almost exclusively from the point of view of this coal, as it would take far too much space to deal with the means of utilising the other fuels above mentioned.

In treating the subject of gas producers as generally applied to the use of coal, it is intended to give only a general outline of the apparatus involved, describing certain particular designs and their methods of operation merely by way of example.

(2) This primarily relates to gas distribution schemes such, for example, as the South Staffordshire Mond Gas Co.'s undertaking. It is not proposed, however, to go into this in detail, but it may be observed that although that pioneer undertaking has not so far been the financial success anticipated, it was launched with great courage and has been supported with great perseverance. The plant used consists of a battery of gas producers of an improved Mond type, which has steadily supplied the surrounding works over a large area of South Staffordshire for the last 22 years. The outstanding result indeed, is that no distribution undertaking has produced so large a yield of gas, tar, ammonia and their derivatives from the many thousands of tons of fuel utilised in it. The use of this gas has obviously been an advantage to the district, otherwise the undertaking could not have continued.

Many difficulties have been overcome during the time of operation of this plant, so that under suitable circumstances there is now no doubt that a project for distributing a low grade gas, made under conditions of highest efficiency, could be launched with commercial success. It would, however, doubtless be a better proposition to distribute a gas of a value somewhere between that of producer gas and lighting gas, *e.g.*, a mixture of producer gas and water gas, having a thermal value of, say, about 250 B.Th.U.'s per cubic foot.

Under these conditions, a certain weight of fuel would yield to the public a very much greater number of therms in the shape of gas than in the case of the high-grade gases as distributed from ordinary gas works, which involve the production of a very high percentage of coke as a residual. This in itself is not necessarily a disadvantage in those districts where coke has a satisfactory market, but coal distillation (whatever the system), although carried on with commendable efficiency, cannot provide the public with anything like as many therms in the form of gas from a given weight of fuel as can be done on a scheme such as herein foreshadowed.

As a general guide the yield of gas in therms from 1 ton of fuel in the three systems mentioned, would be as follows :—

1. Producer gas, 210 therms.
2. Medium value gas of about 250 B.Th.U.'s, 180 therms.
3. High-grade gas from gas works, 70—100 therms.

Limited space prevents the subject of the gasification of coal in gas producers being dealt with in anything like full manner. Indeed, it is quite impossible to do more than hint at the economic advantages to be derived from the utilisation of coal in this way.

Enough, however, has been said as introduction to and explanation of the contributors' chapters following, to indicate that the gas producer must play an important role in the solution of Britain's fuel problems.

Chapter 1.

THE OPERATION OF THE GAS PRODUCER.

WITH THEORETICAL AND PRACTICAL NOTES.

By A. Vincent Kemp, A.M.I.Mech.E.

In considering this section it is assumed that a reasonably good quality coal is employed of small nut grading. The gas producer consists, generally, of a firebrick-lined steel vessel, containing a column of fuel superimposed on a bed of ash, the whole being usually called the "fuel bed." A blast mixture of air and steam is injected through the ash and fuel by means of a suitable blower, its distribution over the whole area of the producer being effected by means of a distributor, as shown, for example, in Fig. 1. The fuel bed has three distinct zones which it is necessary to study carefully in order to obtain an insight into the working of the producer. The zones of a producer are: The ash zone; the oxidation or combustion zone; the reducing zone; the distillation zone.

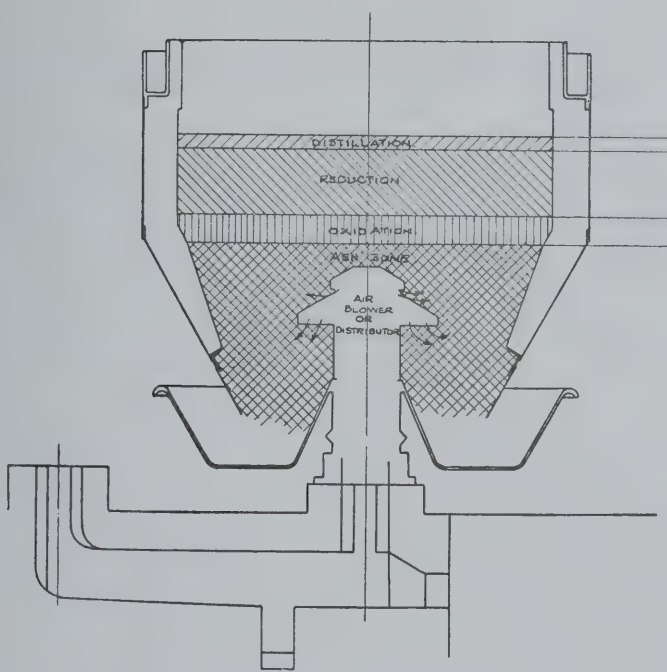
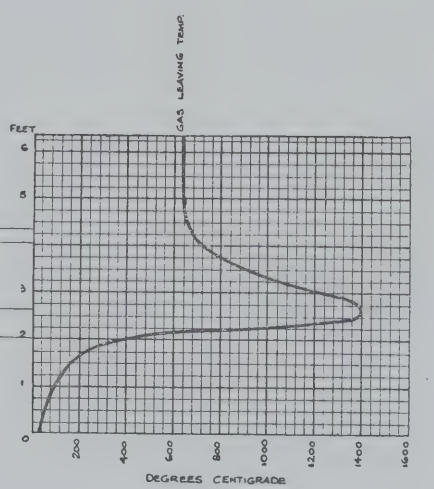


Fig. 1.



Graph 1.

The ash zone.

Function. The ash zone performs three functions. In the first place, it breaks up and distributes the blast evenly over the fuel bed, so that the rate of combustion in the oxidation zone is constant over its area. Secondly, as the hot ashes descend from the combustion zone they impart a preheat to the blast, vaporising any water which tends to condense from the mixture. The third function of the ash zone is to insulate the blower hood or any of the lower plates of the producer which are not lined with firebrick.

Graph No. 1 shows a typical distribution of temperature in the various producer zones. In the particular case shown, the ashes leave the oxidation zone at a temperature of 800° C. and are cooled down well below 100° C. This heat loss in the ashes imparts a "superheat" of about 30° C. to the blast, which enables the reactions in the oxidation zone to proceed with slightly greater rapidity.

Dimensions and Nature of the Ash Zone. From the point of view of even blast distribution the maximum convenient ash depth is required, but reference to the temperature distribution (Graph 1) shows that very little efficiency is gained by increasing the ash bed above 18 inches, the temperature of the ashes then being under 100° C. The third factor influencing the choice of ash depth is the power required to overcome the resistance of the bed. A deep bed may offer excessive resistance to the incoming blast and, in consequence, considerable steam power is used up in overcoming this resistance, so that from the point of view of energy consumed at the blower, whether electrically or steam driven, the ash bed should be as shallow as possible to avoid excessive power consumption. For satisfactory working the ash should be in the form of small lumps (say 1in. size) and as far as possible free from dusty material. Under these circumstances, the blast is well distributed and there is very little tendency for the ash to clog together or to cementate when in contact with the water in the seal. The required quality of ash can readily be obtained by careful control of the temperature obtaining in the oxidation zone.

The oxidation or combustion zone.

The principal reaction proceeding in this zone is the complete oxidation of the carbon to carbon dioxide, the nitrogen in the air blast passing through unchanged: $C + O_2 + (4N_2) = CO_2 + (4N_2)$.

This zone is practically insulated from heat losses; apart from the heat carried by the flowing gases, so that its temperature is very high. This temperature is, however, controlled by the velocity of the air blast and its content of steam, which reacts endothermically with the carbon in accordance with the equation $C+H_2O=CO+H_2$ and in consequence reduces the zone temperature. If, however, excessive amounts of steam are used the zone temperature may be so greatly reduced that the following equation will predominate: $C + 2H_2O = CO_2 + 2H_2$.

This lowered temperature results in unsatisfactory functions of the reducing zone, because an excessive amount of carbon dioxide is then formed and the gases become richer in hydrogen than is generally considered advisable for furnace heating. It is difficult in practice to determine the exact thickness of the oxidation zone, but in an efficiently working producer the thickness is probably not more than six inches. A decrease in the amount of steam results in an increase of temperature and consequent contraction of the zone. The preheat obtained from the ashes also affects the depth of this zone slightly, contraction taking place the higher the preheat temperature. The greatest factor, however, is the reactivity of the carbon. The greater its reactivity, the smaller the oxidation zone and vice versa.

On the practical side, the aim should be to get as high a temperature in the oxidation zone as is consistent with the avoidance of excessive clinkering. An air blast saturated with steam to a temperature between 56° C. and 62° C. is generally found to give the most satisfactory gas without excessive clinker formation. It is doubtful if the increase in quality obtained with saturations below 55° C. compensates for the additional clinker trouble, as the producer requires much more careful supervision, and it is very doubtful if any increase in efficiency is obtained at the furnace.

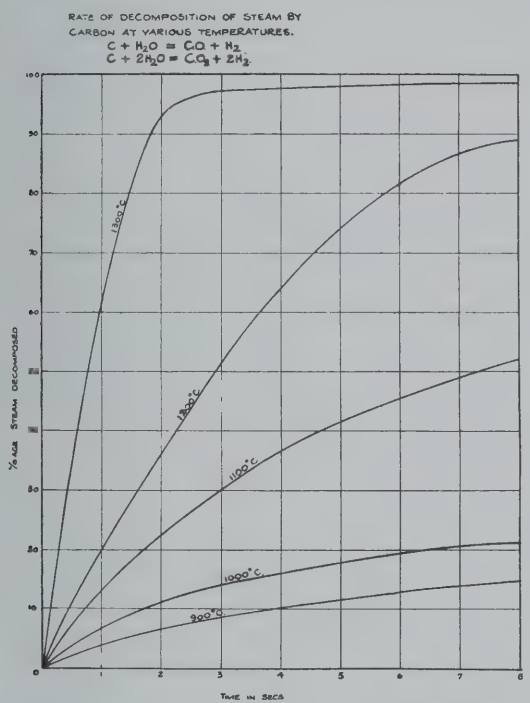
The reducing zone.

The reducing zone is supplied from the oxidation zone with the gases CO_2, N_2, H_2O, H_2 and CO. On passing through the reducing zone the following reactions take place: $CO_2+C=2CO$; $C+H_2O=CO+H_2$; or $C + 2H_2O = CO_2 + 2H_2$. It is not necessary to go deeply into the physical chemistry of the above reactions as this has been done elsewhere, so that a brief statement of the deductions to be made from Graphs 2 and 3 should suffice.

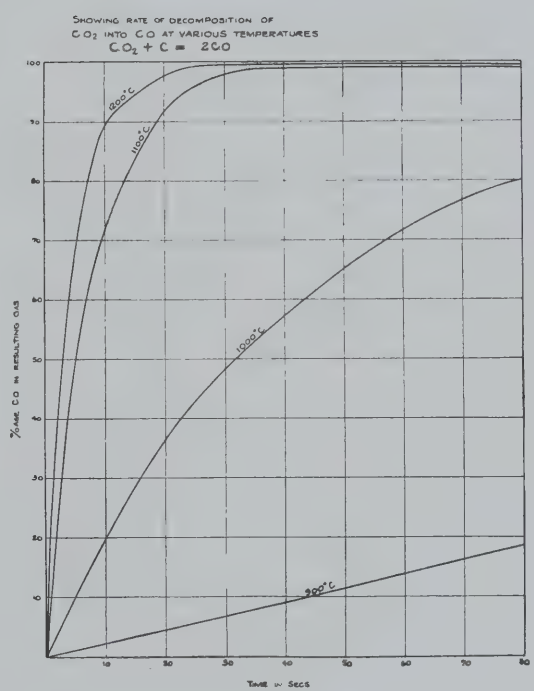
The best gas quality should be obtained: (1) When the temperature of reaction is as high as possible; and (2) when the time of contact between gases and carbon is a maximum. The reader should, however, note carefully that temperature is a much more important factor than time of contact. There are two additional points which vitally affect the gas quality. The first of these may be stated thus: The amount of carbon surface per unit weight of carbon must be the highest practically possible. The lumps of carbon should, therefore, be small in size, and of the highest porosity consistent with density.

A fuel of maximum reactivity should be chosen. The reactivity of the carbon or coke is dependent to a considerable extent on the method of preparation in the distillation zone, prior to its descent into the reduction zone. In practice, we may find that a certain fuel gives its most reactive coke when the latter is prepared at low temperature, in which case the producer is operated accordingly so far as practically possible.

Into the reduction zone there is a continuous flow of heat from the hot gases leaving the oxidation zone. Heat is absorbed from the gases, at first rapidly and then more slowly owing to the endothermic reactions which are carried out in this zone. We have, therefore, a temperature gradient over this zone similar to that shown in Graph 1. As the temperature decreases, the efficiency of this zone decreases owing to the decrease in the intensity of reaction. There is, therefore, only very little to be gained by extending this zone much above 12 to 18 inches. In fact, we might state that the dimensions of this zone more or less automatically adjust themselves and any increase in thickness we may make with this zone is redundant.



GRAPH 2.



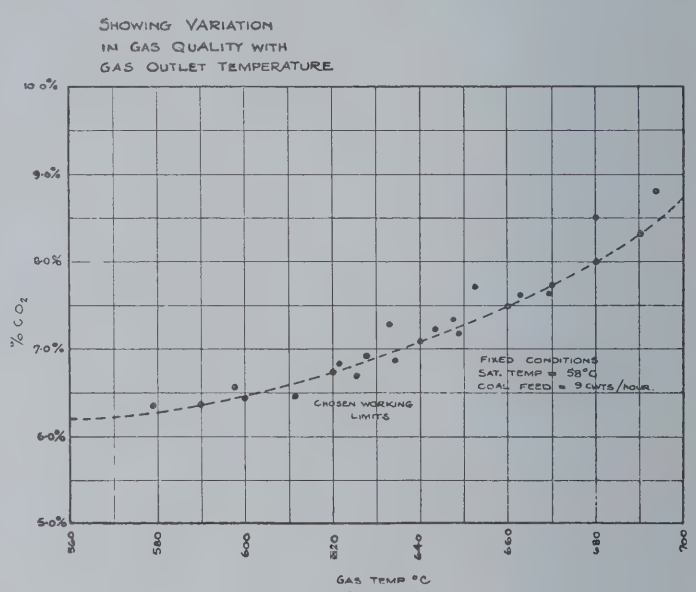
GRAPH 3.

The distillation zone.

The remarks under this head have reference solely to the use of bituminous coals. The gases leaving the reduction zone and entering the distillation zone may be in the region of 800° C. These leave the distillation zone under average conditions at about 600° C. The fuel is, therefore, coked at a temperature of 700° C. This zone prepares the coke for the lower zones and also enriches the leaving gases with methane and hydrogen. The tar vapours distilled from the fuel are also carried away suspended in the gases. Producer gas is mostly used for furnace firing and is generally employed in the hot state, i.e., as near as may be to the temperature at which it leaves the producer (the cooling and cleaning of gas for recovery of by-products and other purposes is treated in another section). In those cases in which the hot gases have to pass through long mains, in which deposits of tar and soot would cause restrictions to the passage of gas, it is advisable to decrease the thickness of the distillation zone and distil off the gases at a higher temperature than usual, so that the tar may be split up into combustible gases and soot. The soot is so finely divided that only a small percentage is deposited in the gas mains, the deposit being readily burnt or blown out of the main during cleaning periods. As previously stated, the reactivity of a coke depends upon its method of preparation. Within limits, it may be said that the slower the preparation

and lower the temperature during distillation the more reactive will be the coke for producer practice. In order to obtain this effect, the gas temperature may be lowered to, say; 450-500° C. by increasing the depth of the distillation zone and, consequently, the time of coking.

For the same fuel under fixed saturation conditions and rate of gasification it may be assumed for practical considerations that the percentage of CO_2 in the outlet gases is inversely proportional to gas quality. In other words, that the higher the CO_2 content the lower the gas quality, and vice versa. From a series of experiments, Graph No. 4 was prepared showing the variation in CO_2 content with gas outlet temperature. The rapid decrease in CO_2 simultaneously with the decrease in gas outlet temperature could not be accounted for by dilution with extra distillation products, as the distillation products were themselves very high in CO_2. Neither could the change be accounted for on the grounds of additional fuel depth giving extra reduction of CO_2, the leaving temperature from the reduction zone being too low for this; further, the increase in depth was negligible. This tends to show that it was owing to increased carbon reactivity, due to preparation of the coke at a lower temperature. This conclusion was confirmed by subsequent experiments, which showed that the maximum gasification rate also increased with the increased gas quality and lower CO_2.



GRAPH 4.

Types of English bituminous coals and the producer.

In producer practice English fuels may be classed as follows:—(1) Free burning; (2) swelling; (3) caking.

(1) *Free Burning.* Free burning fuels generally work well in the gas producer. For these the saturation temperature should be kept fairly low (about 55° C.), so that the fuel bed does not become too open and free, but offers a gritty and fairly heavy resistance to a poker when pushed through the fuel bed. The total fuel bed (oxidation zone+reduction zone+distillation zone) can usually be worked fairly shallow (about 21 inches) with a gas outlet temperature of about 600° C. Care should be taken in controlling the blower with this type of fuel, because the fuel and ash bed offer such a small resistance, that slight increases in steam pressure (if a jet or turbo blower is used) result in a too rapid increase of gasification rate, which if carried beyond the limit result in clinkering troubles.

(2) *Swelling.* Swelling fuels consequent upon their tendency to expand usually cause the fuel bed to become too open or spongy for satisfactory work. Under such circumstances it is advisable to increase the gas outlet temperature to about 680° C., and to decrease the saturation temperature two or three degrees. This will have the effect of decreasing the amount of swelling and closing the fuel bed to some extent.

(3) *Caking.* Caking coals are the cause of most gas producer troubles. When hot, a resinous or tarry film develops on the surface of the particles, which consequently adhere together in a gummy layer and offer an excessively high resistance and give rise to channelling and its following clinker formation. In the gas machine, this gummy layer works itself into balls which ultimately become burnt on the outside, forming clinkers with unburnt centres on the surface of the fuel bed. This can only be avoided by a very high top temperature of the fuel bed. With certain Durham caking coals it is necessary to work with gas outlet temperatures in the neighbourhood of 800° C. The distillation zone is thus kept very thin and the fuel is coked as rapidly as possible. If clinkering occurs with this type of fuel the gas temperature

should be raised still further and the saturation temperature lowered 2 or 3 degrees to assist the further rise in top temperature. If difficulties arise when using this type of fuel, they all are usually the result of nervous handling of it.

Maximum gasification rate.

The maximum satisfactory gasification rate obtained from any particular fuel is, to a large extent, a feature of the properties of the fuel, and to a certain extent dependent on the method of working. As the rate of combustion is increased the temperature in the various zones increases until the ash commences to form excessive amounts of clinker. The maximum gasification rate is therefore limited in practice primarily by clinker when working normally.

The method of preparation of the coke in the distillation zone also considerably modifies the gasification rate by the preparation of a more or less reactive carbon as previously explained. Even apart from these two factors, different fuels have widely varying maximum gasification rates. Fuels with highly caking properties will not gasify so rapidly as free burning fuels, in spite of all the care and attention which may be given to them.

Chapter 2.

NON-MECHANICAL AND MECHANICAL PRODUCERS.

BY A. VINCENT KEMP, A.M.I.MECH.E.

It is generally admitted that producer gas can be made in any apparatus provided with a fuel bed and the means for supplying air and steam blast, and some of the so-called gas producers in use to-day are very crude, and most inefficient.

Generally speaking, it is possible to classify gas producers under two heads, viz.: Non-mechanical, or fixed grate producers; and mechanical or gas machines. It is, however, necessary to subdivide each of these into several sub-headings. There are many types of non-mechanical or fixed grate producers, but most have been developed from the original Siemens and the old Wilson, Dawson and Duff producers. Some were rectangular, some circular, but they differed chiefly in the design of the grate or blast distributor. The fixed grate producer of to-day consists generally of a steel casing lined with firebrick, and provided with a tuyere pipe and blast distributor, charging hopper for the coal and outlet for the gas. The illustration (Fig. 1) gives a general idea of this type of producer, and others of which there are many in use to-day merely differ in some of the details. The process sequence inside this producer is the same as that in the gas machine, and is fully described in Chapter 1.

The great disadvantage with this type is that coal feeding, poking, fire cleaning and ash discharging all have to be done by hand, which is very laborious and costly, and with the majority of such producers each unit must be shut down once a day for cleaning fires and getting rid of clinker. This disadvantage does not, however, apply to some types of fixed grate producer, e.g., Mond, Duff, etc. It will be obvious also that the rate of gasification per sq. foot of producer area is very limited. As a matter of fact this figure very rarely exceeds 20 lbs. of coal per sq. foot per hour, and in many cases is considerably less, whereas with a gas machine it may be as high as 70 lbs. of coal per sq. foot per hour.

All these disadvantages are very serious, but the reader must not lose sight of the fact that the first cost of this type of producer is small as compared with that of the gas machine. It is hardly necessary to trace the development of this producer from its infancy, but it may be of use to enumerate some of the various designs in operation to-day. As stated above the chief variation in the several types is in the design of the grate, and it will be best to classify some of the best known under the heading of grates.

FLAT GRATE PRODUCERS: Smith Gas Engineering Co.'s shaking grate; Crossley gas producer; National Gas Engine Co.'s Gas Producer; Hermansen's flat grate.

INCLINED STEP GRATES:—Siemens; Wellman; Hermansen; Stein & Atkinson.

DIAMETRAL GRATES:—Duff and various modifications thereof.

CIRCUMFERENTIAL GRATES:—Mond.

CENTRAL GRATE:—Dawson; Wellman; Power-Gas Corporation; Taylors; Stein & Atkinson.

The central grate is the most popular and, with the exception of the circumferential Mond grate, is the one which allows the best facilities for ashing and clinkering, thereby giving the nearest approach to continuous working.

The best design of grate is certainly that which, while having only a low resistance to the air blast, affords the most even distribution of blast through the fuel bed and in addition provides the easiest facilities for clinkering and ashing.

Slagging producer.

Various attempts have been made to develop a successful slagging producer, in which the ash is run out in a molten state by means of adding lime, or other material as a fluxing or slagging medium to the fuel charged, but the difficulties experienced in keeping the slag liquid, particularly when shutting down periodically, and the enormous upkeep costs have proved very detrimental to such development. This producer is usually much deeper than the ordinary fixed grate producer and is blown with tuyeres like a blast furnace. It is more elaborate in design and more difficult to control, hence it has not made the advance it otherwise might have done. Another disadvantage is that owing to the extremely high blast pressure required, an excessive amount of dust and small coal is blown over into the gas mains, necessitating continual cleaning, which is not advisable where continuous working is required.

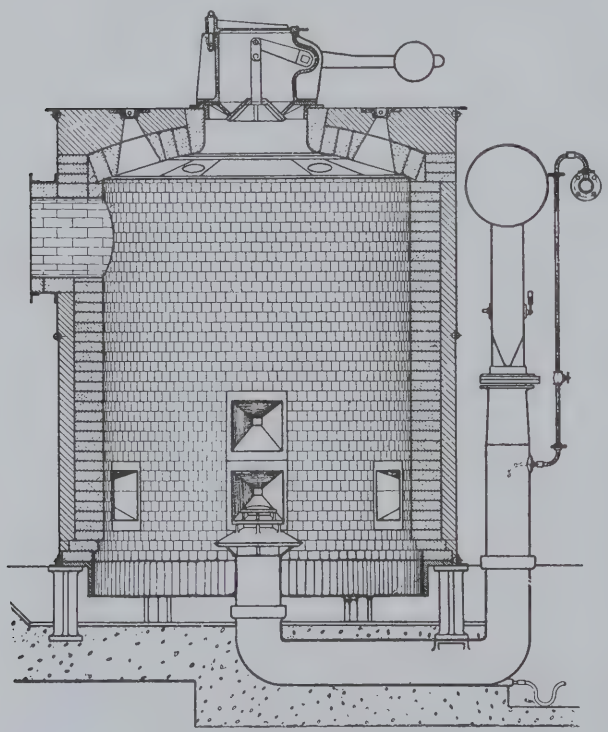


FIG. 1.—*The Fixed Grate Producer.*

Sphere of action of the gas machine.

A similar relationship exists between the old type of hand-fired boiler and the modern chain grate stoker, as between the fixed grate producer and the mechanical gas machine. It is not intended to deprecate in any way the merits of the fixed grate gas producer, since for the particular work for which it is designed the fixed grate producer performs its functions with quite adequate regularity and efficiency. The sphere of action of the gas machine is, however, clearly defined.

1. It supplies a much greater quantity of gas per unit area than the fixed grate producer.
2. It reduces labour costs for cleaning and feeding.
3. It supplies a constant quantity of gas of fixed quality, and is free from the surging effect and consequent efficiency loss due to irregular feeding on the fixed grate hand-fed type.

The gas is of higher quality owing to the constancy of the gas machine lending itself more readily to efficient control and on account of point 3 gives economy in fuel consumed.

We may, therefore, state that for installations in which economy, labour costs, high gas quality and constancy are essential, the gas machine shows considerable advantages over the fixed grate producer.

SEMI-GAS MACHINES.

The addition of a fuel levelling device with or without automatic or mechanical feed can hardly be said to constitute a gas machine, and the same may be said in reference to the mechanical grate and air distribution with or without the ash remover. Nevertheless such additions give certain of the valuable characteristics of the gas machine.

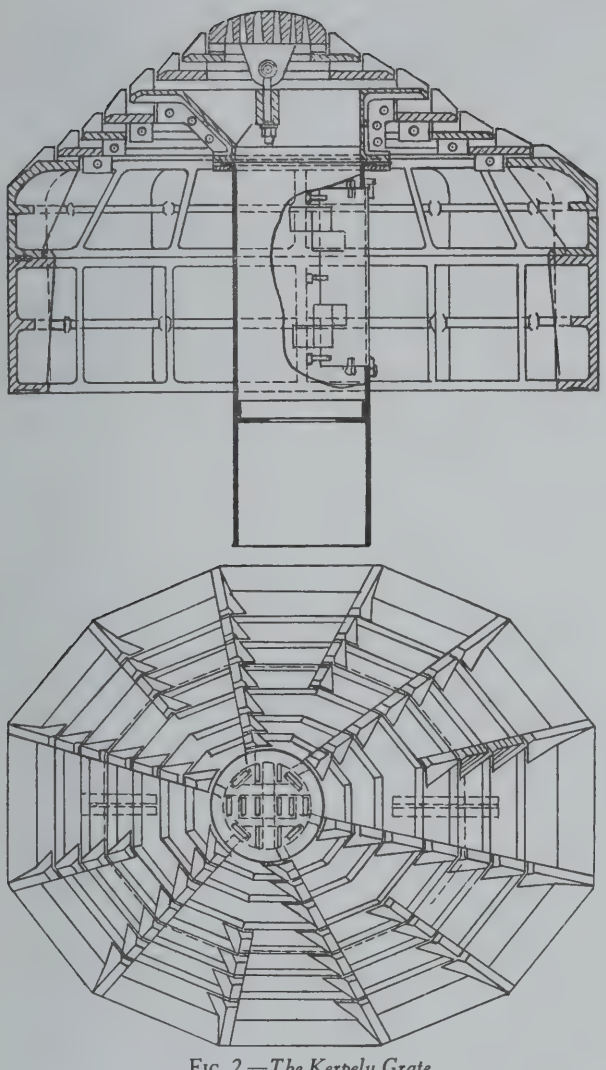


FIG. 2.—*The Kerpely Grate.*

Two well-known examples of the latter may be cited, viz., the Kerpely and the Lymn-Rambush grates, of which a brief description is here given.

Kerpely grate.

This grate is shown in Fig. 2. It will be seen to possess a polygonal oblong base with vertical sides, upon the top of which is placed an eccentric and unsymmetrical pyramid made up of a series of hematite iron segments, about 1½in. thick, built on top of one another and held together with a central bolt. Each grate segment is interlocked with the two adjacent ones, thus forming a rigid structure. The grate is mounted on the base plate of a water lute which revolves on a ball race and is rotated by means of worm gearing. Ashes are discharged by a shovel generally made in two parts, a back plate riveted on to the lute plate of the producer, and a movable shovel which is caused to slide up and down by means of a screw and hand wheel.

Lymn-Rambush grate.

This grate is shown in Fig. 3 and is placed concentric to the axis of revolution. It consists of four symmetrically eccentric hematite segments, designed to break up the clinker against the producer at four points during each revolution previous to its discharge into the outer annular space of the water seal and ash bowl. In this construction the strains are diametrically opposed to each other and therefore balanced; this is important, as it avoids a great deal of wear which exists in those producers having a grate involving a single eccentric action. The top surface of the grate is made of several hematite iron sections of helical contour, whereby, on revolution, the lower part of the fuel bed is submitted to continuous, but very slow, vertical movement up and down, which maintains a uniformly compact bed of fuel, and prevents channelling. The ashes flow freely down a series of interlocked grate bars, the openings between which always move away from the fuel, thus preventing clinker or ashes accumulating, and clogging up the ambushed air ports of the grate. On the outer circumference of the base plate of the water seal which carries the grate is a rack operated through a worm and friction gearing by a single steam cylinder. The grate and water seal are supported and guided by a series of rollers.

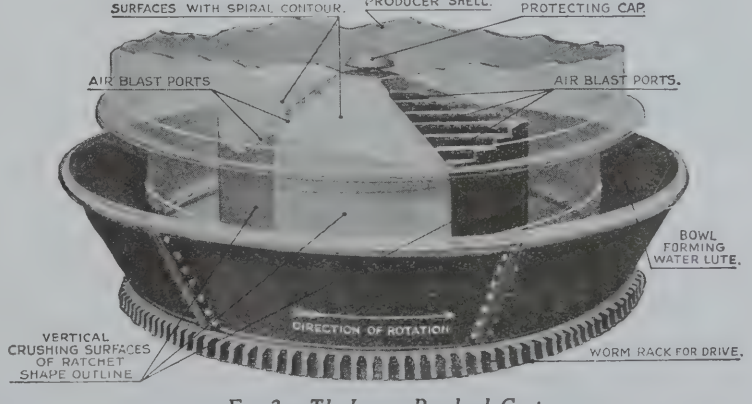


FIG. 3.—*The Lymn Rambush Grate.*

The ash is removed from the seal by a number of inclined adjustable ploughs, by which it is discharged over the sides of the bowl into a wagon. The speed of rotation of the grate and the ash bowl is controllable to suit the requirements of the fuel as to ash content and rate of gasification.

THE GAS MACHINE.

The main points aimed at in the design of a gas machine (as indeed also with the semi-gas machines) is maximum gasification rate and saving of labour. The gasification rate, excluding the case of the liquid slag producer, is primarily limited by the formation of excessive quantities of large clinker. With the static producer, one point in the fuel bed may reach this maximum point long before the gasification rate at other points is reached, which to a less extent applies also to the semi-gas machines. The complete gas machine is therefore designed with a view to equalising all the following factors over the whole area of the fuel bed.

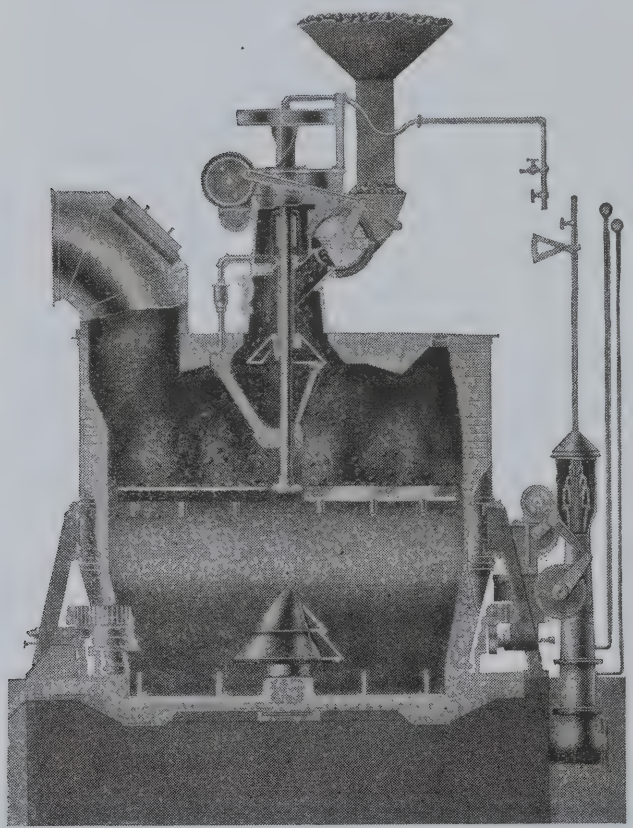


FIG. 4.—*Chapman Gas Producer.*

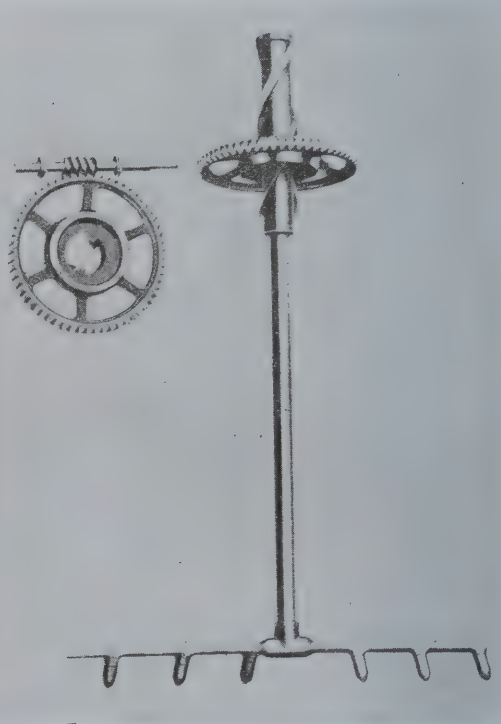


FIG. 5.—*Chapman Gas Producer.*

Blast Distribution. Uneven blast distribution is one of the most prolific causes of uneven gasification rate. The air orifices in the blast distributor must be carefully designed to give the required amount of air at the required point, and to avoid the orifices becoming choked with ash. For example, in the three-hood blower shown in Fig. 6 the area of orifice X is designed to supply the air and steam mixture to the centre of the bed, orifice Z is designed to feed the outer edge, and Y the intermediate points. The angle of the plates forming the blower is of great importance in throwing the blast to the required point.

Ash Bed. Provision must be made to enable an ash bed of at least 12in. to be worked. Any unevenness in blast distribution can then be evened out so that on entering the combustion zone, the amount of air and steam mixture may be constant over the whole area of the producer.

Feed. For satisfactory working it is very essential that the feed should give an even and constant distribution of fuel over the surface of the fuel bed. The greater part of the resistance of the fuel bed lies in the distillation zone, so that unless this zone is of constant thickness, channelling through the thinner parts takes place.

Agitation. The necessity for agitation is debated by many authorities. Nevertheless, the high gasification rates obtained on gas machines fitted with pokers actually operating within the fuel bed, are strong arguments in favour of agitation for obtaining high gasification rates. The agitating bar certainly prevents caking and clinkering to a very considerable extent. When local channelling occurs clinker is bound to result, but when the agitating bar is used, the channels are filled up, and the extremely hot fuel distributed to other parts of the producer.

There are numerous gas machines in industrial use on a considerable scale amongst which may be mentioned the Chapman gas machine, the Morgan gas machine, the Wellman gas machine, the R. D. Wood gas machine. Two of these are described by way of example.

The Chapman gas machine.

The Chapman gas machine illustrated in Fig. 4 is the direct outcome of the Chapman agitator, already referred to.

Coal Feeding. The feed consists of a revolving drum with three pockets, and is operated through a connecting rod from the spur gear through a pawl and rachet in which is an effective safety device of an interesting type. The speed of rotation is controlled in a simple manner by changing the position of the quadrant which keeps the pawl out of engagement with the rachet wheel, thus controlling the effective stroke of the pawl. Each dump of coal, by means of a specially designed chute and bell, is distributed evenly over the whole surface of the fire-bed, which is claimed to be an important and unique feature.

Agitator (Fig. 5). This consists of a water-cooled T-piece, the horizontal portion of which operates slightly under the surface of the fuel bed. Stirring fingers are attached to the under side of the horizontal portion. These dip into the fuel bed and agitate it. The agitator is revolved by means of a toothed wheel attached to the vertical shaft. The agitator has also a vertical motion which enables the agitator to move up as the height of the fuel bed increases in between ashing-out periods. The agitator is driven by a small electric motor, which is also geared to the coal feed drum. By adjustment of the driving pawl, the rate of revolution of the drum, and therefore the rate of feeding of the fuel, may be varied to suit any requirements. The makers claim that the agitator is maintained at a constant depth below the surface of the fuel bed (base of stirring fingers about 12in. below fuel bed surface) by means of a weight on the vertical shaft, and that should the agitator meet any clinker, it rises until the resistance to its motion is reduced.

Ash Removal. The ashing beam itself is a massive steel casting which rotates continuously in the ash bosh of the producer, its speed being readily adjustable to suit the required rate of gasification and the quantity of ash in the coal in use. It has teeth formed on it for the purpose of crushing any clinker formed, and renewable lugs or fingers extending upwards into the ash bed to impart motion to the ashes and the lower part of the fire bed, keeping the whole homogeneous and preventing bridging or channelling. The ashing beam as it revolves pushes the ash towards the exterior of the producer, and owing to the "set" in it removes an equal amount of ash from every part of the ash bed; any clinker formed is fetched down by the fingers, crushed by the ashing beam and ejected with the ash into the bosh outside the producer. From here it is carried round on lifters to the desired dumping spot, where the ash is scraped off these lifters by a plough and deposited into skips. The ashing beam and lifters are bolted to a massive gear ring which is carried by horizontal and vertical rollers. The drive is imparted to this gear ring by a motor and suitable reducing gear similar in design and construction to that of the agitator, a safety device being incorporated; all bearings are external to the producer, accessible and efficiently lubricated.

Results for a year's continuous working show an average of CO_2 under 5 per cent. and for CO over 28 per cent. These results are attributed to the combined stirring and levelling of the arm, the frequency of agitation from the agitator, the even distribution of the feed, and the agitation of the lower part of the fire-bed, coupled with continuous removal.

The Wellman gas machine.

The Wellman is a type of gas machine in which the whole operation of gas-making is entirely automatic (see Fig. 6).

Coal Feeding. Coal feed is effected by two revolving drums A and B, the speed of both being variable and controlled by a simple hand wheel so that a suitable quantity of fuel, determined by consumption requirements, is fed in. The speed of the feed system is so arranged that the fuel is delivered in small quantities at frequent intervals. The fuel bed thus receives a thin even coat on each revolution of the machine.

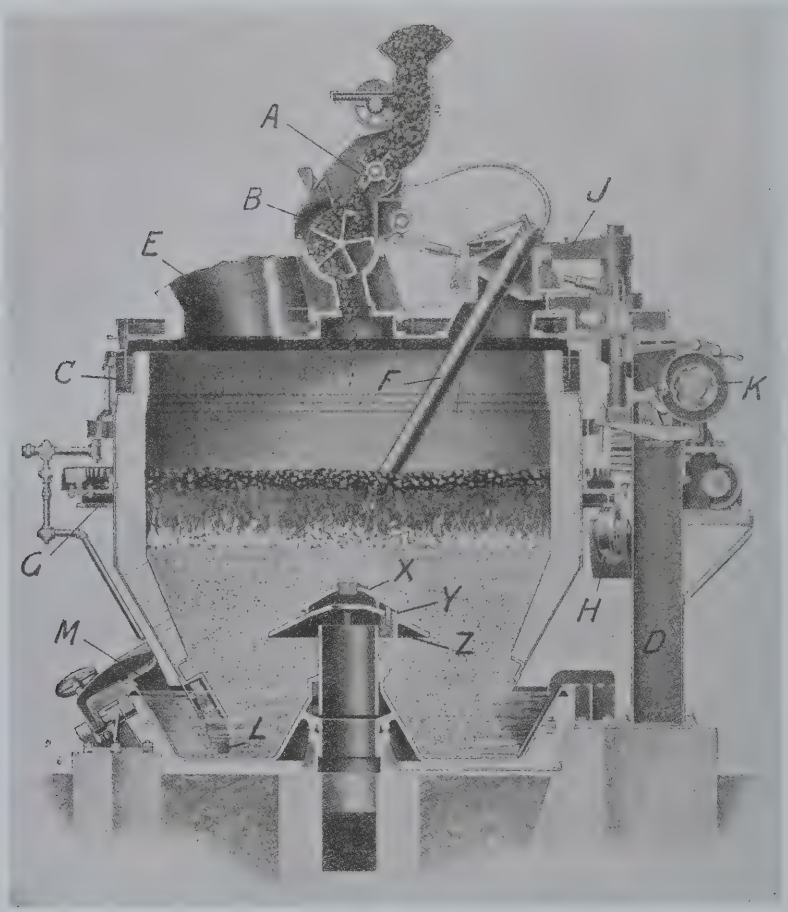


FIG. 6.—*The Wellman Gas Machine.*

Shell. The shell of the machine is divided into two parts which are made gas tight by means of a water seal C. The upper part or top plate is stationary, and is water-cooled. It is rigidly supported by three stanchions D and on to it are fixed the gas outlet main E, the feed B, and the agitator F. The lower portion of the shell is brick-lined and is rotated once every four minutes by means of the toothed rack G, suitably geared to an electric motor. The weight of this portion of the shell is taken by articulated flanged wheels H supported on the stanchions D. The lower portion of the shell is tapered, and dips into a deep water seal contained in the pan.

Agitator. The agitator is a steel bar F cooled by water passing down the centre. The bar oscillates in an arc from the centre of the bed to the side wall. It is driven by the toothed arm J at a suitable speed to give satisfactory agitation. The tip of the poker is made of special steel screwed and welded into the barrel of the bar, so that high temperatures can be used without danger of the poker end being burnt through.

Pan and Stop. The pan is of cast-iron, and is carried on a ball-bearing path of large diameter. It is driven by the torque transmitted through the ash bed. The pan is automatically stopped for $\frac{1}{8}$ of a revolution when desired by means of the cam K.

When the ash bed becomes too thick, the pan stop is let into action by means of a chain. The intermittent stopping of the pan, combined with the scraping effect obtained by the scraper L, slowly removes the ash from the inside of the machine into the pan and from there it is removed from the machine by a plough blade M.

The blast distributor XYZ is rigidly attached to the pan and revolves with it. The apertures in the blower are adjustable while the machine is in operation, so that any excess gasification rate at the sides or centre can be simply adjusted. The air for the blower is supplied either by a turbo blower or jet blower.

The gasification rate of the machines varies with the area inside the brickwork and also with the type of fuel used. With free burning fuels a machine with an internal diameter of 10ft. 6in. can gasify 55 cwts. per hour (i.e., 70 lbs. per sq. foot per hour). With heavily coking fuels this rate may fall to 40 cwts.

This machine is completely automatic from coal feed to ash discharge and provides for the necessary poking of the fuel bed mechanically and will give a comprehensive idea of the latest type of gas machine. There are many other machines fitted with mechanical coal feeding and levelling arrangements and automatic ash discharging devices among which are the following:—Bamag, Bentley, Enrhadt and Sehmer, Hilger, Hughes, Kerpely, Lymn-Rambush, Morgan, Rehman, R. D. Wood.

When considering the question of the best type of apparatus to instal for gas-making, the problem should be studied carefully from the following standpoints:—

Quality of coal.

If this is of a free-burning nature of correct size free from dust and with a low percentage of ash, and the supply is regular in quality, then either non-mechanical or mechanical producers will serve, and other conditions such as first cost, labour, etc., will decide the question. If, on the other hand, the coal is highly caking, then only a machine will operate successfully and continuously.

Ash content.

If this is very high, then provision must be made for automatic discharge, and if the ash has a low fusing point, a mechanical poking device should be provided. A properly designed eccentric mechanical grate such as above described will generally avoid clinker troubles.

Labour.

This is a most important feature, and should be given careful consideration. If labour is scarce and costly, then gas machines should certainly be adopted and provision should be made for expert supervision of the plant when running.

It may be assumed that a fixed grate producer plant gasifying 4 tons of coal per hour will require a labour force of 3 or 4 men per shift for operation, and a machine plant of the same capacity will need only one man per shift with the occasional help of a further man during day shift only, so that with the latter plant a nett saving of 8 men per week is effected.

Chapter 3.

CONTROL OF THE GAS PRODUCER.

By A. VINCENT KEMP, A.M.I.MECH.E.

The efficient working of the gas producer or gas machine is a simple matter provided it is carried out under the supervision and control of capable management.

Fuel—bituminous coal.

It is quite probable that the gas machine can make good gas out of raw material unsatisfactory for use in the static gas producer, but in considering the relative merits of the two types the management would do well to remember that the gasification rate in the former falls considerably when poor fuel is used, and to examine carefully the following points.

Does the cheaper operating cost per B.Th.U. in the low-grade fuel justify its use after allowing for the additional capital charge for extra plant. Under this heading subsidiary costs such as extra bunkering and fuel handling costs, as well as extra ash removal, should be carefully considered.

What additional labour costs in the case of the static producer are involved? With caking coals high in ash the fuel bed must needs be poked continuously and the ash bed "cleaned down" much more frequently.

An important item to be considered with static producers is the production loss during shut-downs owing to "clinkering." Under such circumstances, production may cease for hours while the producer is cleaned out and restarted.

Generally speaking it may be said that in cases where a battery of producers is available, experiments with lower grade fuels are often the means of great saving in the fuel bill, but in cases where a single gas producer or machine is a vital factor in the production of the finished article, it is cheapest in the long run to pay a good price for a good coal.

Grading. Fuel grading is a very important item. "Fines" should be avoided as far as possible, as these ultimately find their way to a large extent into the gas main, causing back pressure on the producer and therefore excessive blower power or steam consumption. With a gas producer or machine gasifying at a high rate any "fines" in excess of 20 per cent. are likely to cause trouble unless frequent cleaning or burning out is resorted to. For rapid gasification $\frac{1}{2}$in. nuts are very satisfactory, and for slower gasification rates the larger nuts give every satisfaction, providing there is no tendency to block the feeding arrangements.

Fuel characteristics.

A free burning, more or less non-caking coal always gives the best results in the gas producer. The static producer is not able to deal with badly caking fuels owing to the large amount of poking necessary; on the other hand, the gas machine is able to deal fairly satisfactorily with caking fuels owing to the automatic agitation, but even in this case, satisfactory trouble-free working can best be obtained with a free-burning fuel.

Ash.

The fusion temperature of the ash has an important bearing on satisfactory results. The melting point obtained in the laboratory is not of very great assistance, mainly owing to the fact that the melting point in the producer is obtained in the presence of finely intermixed carbon particles, while that in the laboratory is under carbon-free conditions. Analysis of the ash from the producer gives some indication. An ash high in silica and alumina and low in lime and iron should always be chosen in preference to one containing high percentages of the latter constituents.

The tendency of the ash to cementate on the concrete bottom or pan bottom, caused by high percentages of sulphate in the ash, should be noted. Many ashes form this hard deposit on the bottom of the producer when brought into contact with water, and thus restrict the free outflow of ashes. Some gas machines are fitted with special scrapers to eliminate this trouble; others are not so provided, while the static producer is unable to deal with this trouble at all.

The mixing of fuels.

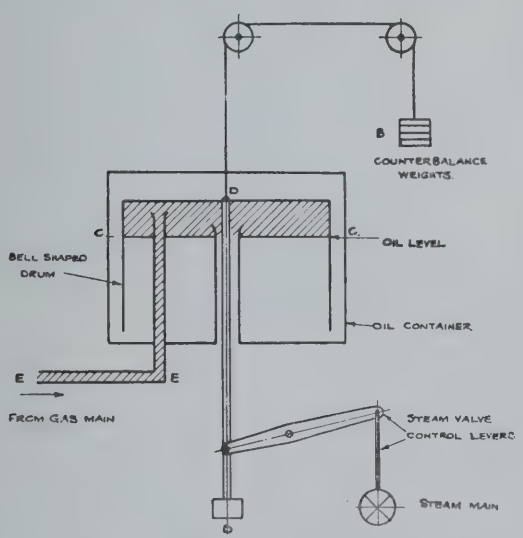
The practice of mixing fuels is bad from a practical standpoint owing to the difficulty of obtaining accurate distribution of the component fuels throughout the mass thereof. Moreover, the successful operation of a producer depends upon the various zones being kept more or less separate and even. In the case of mixed fuels, the rate of combustion of one fuel may be much greater than another. The temperature distribution then may become very uneven, owing in practical operation to the zones of the individual fuels being of different thicknesses, or to there being pockets of each in different parts of the fuel bed. The combustion zone of one then becomes mixed up with the ash zone of the other and clinkering troubles result. In the second place, it often occurs that the clinkering point of the mixed ashes is much lower than either of the components; in other words, the ashes may form an eutectic mixture.

Variation in fuel quality may also affect the producer adversely in a similar way to the mixing of fuels, so that care should be taken to see that the fuel is supplied from the same pit, and, if possible, the same seam.

Air and steam blast.

This is best regulated by the simple method of maintaining a certain temperature of steam saturation, thus having a scientifically accurate measurement.

The temperature of the air-steam blast should be taken by a permanently fixed mercury thermometer, with a dial recorder. This should be accurately standardised at a prearranged figure between the limits of 50° C. and 70° C. (except in the case of by-product recovery producers), and be graduated so that $\frac{1}{2}$° C. between these limits can be easily read. The position of the thermometer bulb should be well away from the steam injector, so that the proper mixing of air and steam can take place before the thermometer is reached, and also away from the superheating influence of the producer itself. A suitable temperature should be determined by trial to suit the particular coal and operating conditions and the producer worked within $\frac{1}{2}$° C. of this standard. The average run of English fuels require a saturation temperature between 58° C. and 62° C. With badly clinkering fuels, a saturation temperature of 64° C. or even 66° C. may be necessary. On the other hand, certain Staffordshire coals will stand saturation temperatures as low as 56° C. or less. When the rate of gasification is raised, the rate of generation of heat in the oxidation zone increases. Heat concentration takes place, and the temperature rises. In consequence the saturation temperature must be raised slightly to again reduce the zone temperature back to normal. On the other hand, the ash in making its way downward more rapidly is taking more heat from the oxidation zone, which modifies again the necessary rise in saturation temperature. If the gasification rate is decreased the saturation temperature should be decreased.



Sketch showing principle of Gas Regulator.

Gas temperature.

A thermocouple placed in the outlet neck of the gas producer or machine soon repays the cost of installation. In the first place, the actual temperature will depend upon many factors. With non-caking fuels 600° C.—650° C. usually gives satisfactory conditions; with caking fuels 750° C. or higher may be reached in practice; with comparatively restricted size of gas mains leading from the producer to the furnace, it is advisable to use a low temperature so that the volume of the gases is decreased and the velocity will be decreased in proportion. There will then be less tendency for an excessive amount of fines to be carried up into the main. Further, the radiation loss from the main is not so great with lower temperatures as with higher ones. The temperature gradient from producer to furnace will then be less and the reduction in velocity along the main will follow a similar curve to the temperature gradient. With a fairly constant velocity, very little dust will be deposited in the gas mains. On the other hand, the construction of the furnace to be fired may require a high gas temperature and under such circumstances a high temperature at the producer outlet may be necessary. With some plants, it may be necessary to avoid tar deposition in the mains owing to a short burning out period at the week-end being insufficient. Under such circumstances, a gas outlet temperature of 750° C. will be advisable to decompose any tar present in the gas and leave only a fine soot which can readily be burnt out.

Fuel and ash depth.

In so-called hot producer gas practice it will be found that with saturation temperature and gas temperature fixed, the fuel bed will more or less find its own depth. The modern gas producer with its shallow fuel bed and high quality gas has plainly shown that except for by-product recovery the older

ideas of enormous fuel beds, seven or eight feet deep, are unnecessary. In fact, it is extremely difficult to understand how such beds could be obtained unless the producer were filled up with green coal performing no function whatsoever except to cool the outlet gases unduly. With the gas machine, the maximum ash depth will be fixed by the distance between the top of the blower and the end of the agitating bar where this is adopted. It is then not advisable to attempt to work the end of bar down into the ash bed. In practice it is found that a 12-in. ash bed gives satisfactory blast distribution. In the case of the static producer the combustion zone is not usually absolutely level, so that it is advisable to use an ash bed of about 24in. to avoid any possibility of the blower or lower plates becoming overheated.

Pressure control.

In many cases, it is very essential that the volume of gas should be constant over a prolonged period, and secondly that when any one of the furnaces receiving the gas is shut off, then the output of the producer should automatically be cut down to supply the correct demands of the other furnaces. The figure presented shows the principle upon which all the pressure regulators are based. A is a gas-tight cylindrical bell floating in an oil bath CC. The weight of the bell is counterbalanced by the weights B, and a rigid rod DD is fixed to the floating bell. The inner side of the bell is connected to the gas main by the pipe EE. The lower end of the rod DD is fixed to a valve placed in the steam main. Assuming the system is balanced by a pressure of 1in. in the gas main, let us suppose that the pressure rises $\frac{1}{10}$in. The bell then rises owing to the greater pressure inside. The rod DD rises and thus cuts down the steam supply.

The pressure necessary in the gas main depends first and foremost on the gas consumption requirements, but also on other factors, such as length, bends, area of mains and flues, etc., but the smaller the pressure in the main, the less will be the steam consumed at the blower. It is generally between one-inch and four inches water column. No difference in gas quality can be detected when the main pressure is high or low. The pressure regulator is usually placed so that the output of a whole battery is varied with varying demands. Rapid variation in air and steam blast is a disadvantage to the satisfactory operation of the producer. In the first place, unless the producer men are very conscientious, the feed is left on and the machine is overfed when the air and steam blast is reduced. Then again, variable blowing tends to form clinker, owing to the consequent variation of the saturation temperature. It is sometimes preferred in cases where fluctuations are not great, to standardise the blast pressure on all producers but one, and allow the regulator to control one producer or machine only. The operator is then able to pay more attention to the one which is likely to give him the trouble.

Blast pressure.

A simple U-tube pressure gauge fixed to the blast main will give useful indications as to the operation of the producer and its internal condition. The pressure readings vary from the following causes:—

(1) Altered gasification rate with its increase or decrease of air blast. The readings increase with increase in gasification rate and vice versa, but there is no direct proportion between the two.

(2) The readings increase with increased resistance in the system; this may be due to an increase in depth of the ash or fuel beds, due to irregularity in cleaning down the ash bed or over-feeding the fuel bed, clinker in the combustion zone, or sooting up in the gas main. When any unaccountable increase in pressure takes place, all these possibilities should be looked for.

(3) When the blast pressure is much below normal, the fuel bed is probably being worked too open and local channelling will soon occur. Mechanical or hand poking should then be resorted to to solidify the fuel bed, while the saturation temperature may be advantageously lowered to make the fuel bed more compact.

Records.

In all cases, it is advisable to keep an hourly record of all instrument readings, together with the depths of the ash and fuel beds. The operator is then kept alive to his duty and the causes of any troubles can be traced.

Chapter 4.
AUXILIARY PLANT AND EQUIPMENT.

By A. Vincent Kemp, A.M.I.Mech.E.

Blowers.—Producers both mechanical and non-mechanical may be blown in three different ways:—

(1) By steam turbo blower, the exhaust steam from which is utilised for saturation of the blast.

(2) Electrically-driven centrifugal fan or Roots blower with steam added from external source.

(3) Steam jet blower.

Two of the best known turbo blowers in connection with producer plants, are the Coppus and the Carling, both of which are American productions. They are very reliable, easily controlled, and give satisfactory and continuous service.

The simple steam jet was the first means of blowing producers, but this has been developed and improved in recent years, and the latest steam blower shown in Fig. 1 is wonderfully efficient compared with the old-time solid jet. The curves shown in Fig. 2 give the comparative results obtained with the old type and the new.

Poke Holes. Constant poking of the fuel bed is necessary on fixed grate producers, and this is very arduous and unpleasant work on account of the escape of gas through the poking holes. Several devices have been used to improve matters in this direction, amongst which is the P.G. steam-blown poking hole.

The device consists of a poking hole fitted with an annular steam jet and ball plug cover. The steam jet is arranged so that when the hole is covered by the plug, the jet and steam valve are both outside the producer and

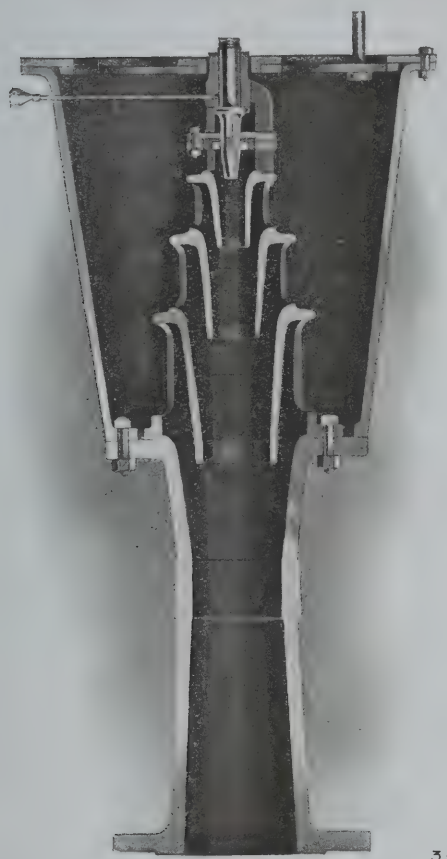


Fig. 1.—*Cross Section of Blower.*

not subject to the heat and tar as in other devices. The act of opening the poking hole turns on the steam, and is quite automatic. The steam jet keeps the gas from coming out of the producer and enables the operator to work in comfort and see that the producer is functioning correctly. The whole apparatus is of robust construction without any delicate parts to get out of order. The lid or plug can be kicked open or shut without danger of damaging the jet or steam valve. The apparatus is self-contained and can be fitted

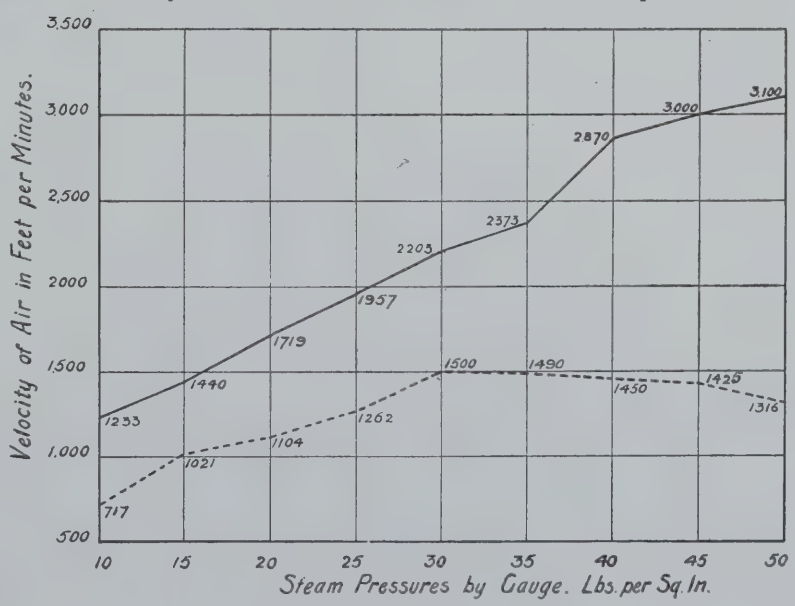


Fig. 2.—*Efficiency Curves of Blowers.*

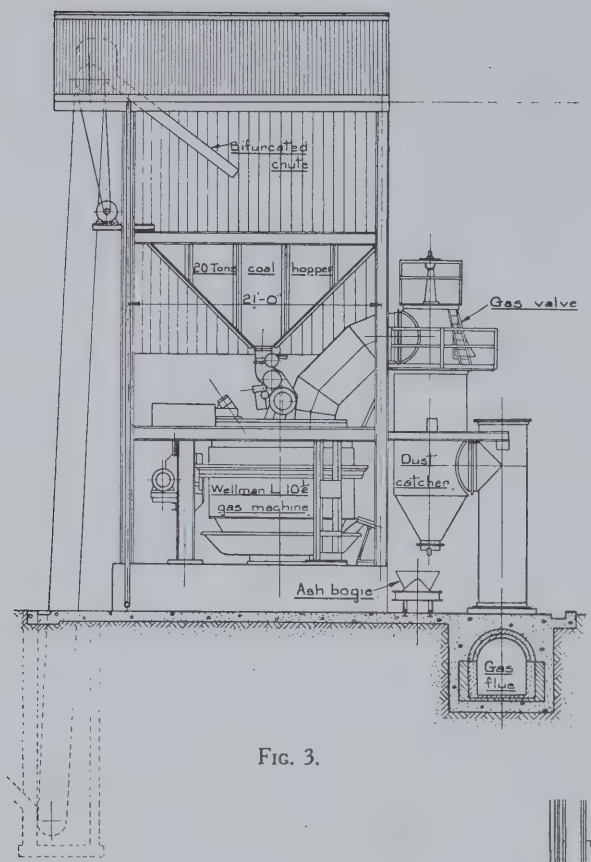


FIG. 3.

to any existing producers in place of the present poking holes and will work with any pressure of steam down to 30 pounds per square inch.

Except when cooled and cleaned for power purposes or for distribution through a system of small mains and valves or for recovering by-products the gas is conveyed directly to the furnaces, as hot as possible, its sensible heat being conserved to the maximum extent; hence the gas mains should be lined with firebrick, and if the additional expense is warranted they should also be insulated.

Underground Flues. If the gas is conveyed underground, brick flues (Fig. 3) are generally used, in which case an insulating brick may be built either between the firebrick lining and red brick backing, or form part of the backing itself.

Overhead Mains. If the gas is conveyed overhead, steel mains lined with firebrick (Fig. 4) are generally adopted, and in this case insulating bricks may be placed between the plate and the firebrick lining.

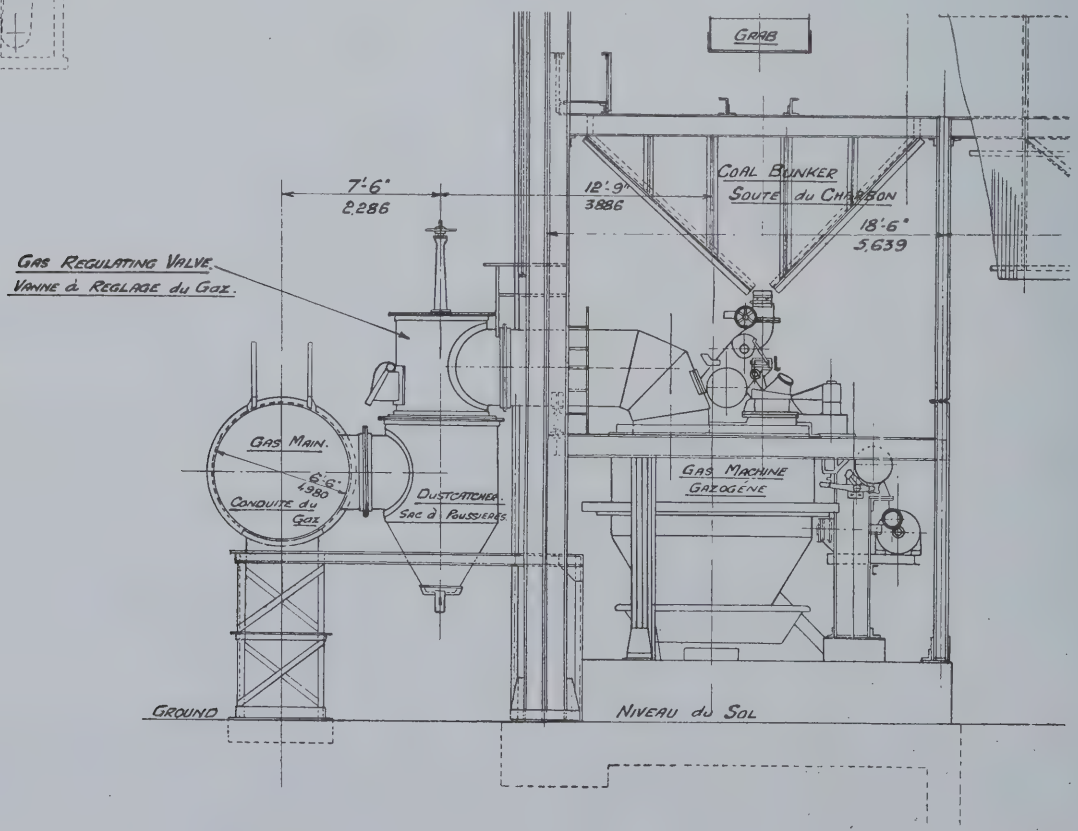


FIG. 4.

Special care should be given to the question of dust-catchers, cleaning and explosion doors, etc., in order that the mains may be kept free for the passage of the gas.

Periodical clearing mains.

Most gas plants can only be shut down at week-ends; therefore the hot gas mains must be so arranged that they will easily run for a week without possibility of choking up, and any special points liable to choke up quickly should be provided with cleaning devices which can be used while the plant is in operation. Special arrangements must be provided for burning out the gas mains in the time available at the week-end, and these usually consist of a connection from the main direct to the nearest chimney through a valve that must be absolutely gas-tight when closed. The spectacle valve and the quadrant valve are excellent for this purpose. An explosion door should be provided at the extreme end of the main, furthest away from the chimney, for the admission of air for burning out the soot, tar, etc. This explosion door also serves the purpose of clearing the main of air or explosive mixture when starting up, as it may be left open a few minutes until only gas is seen issuing

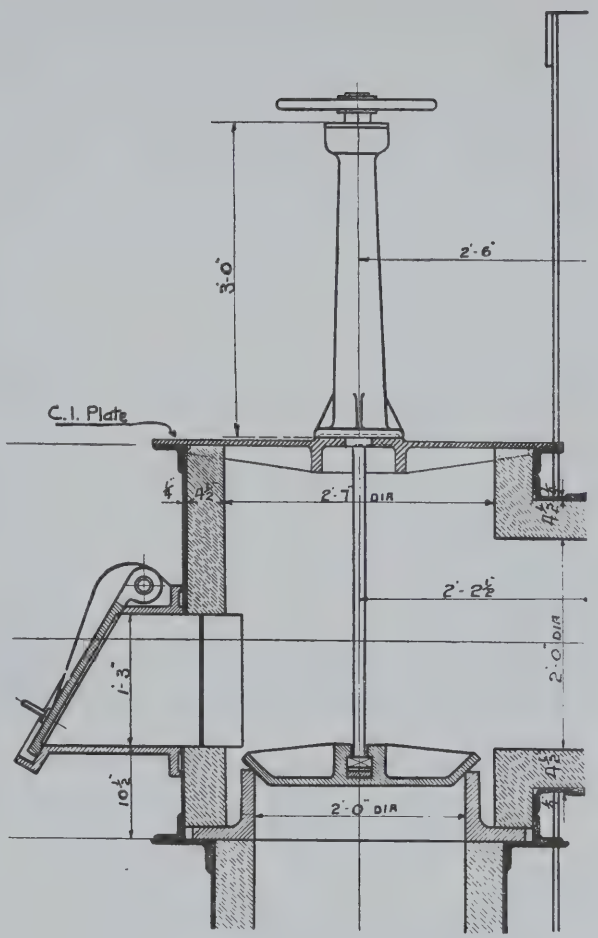


FIG. 5.

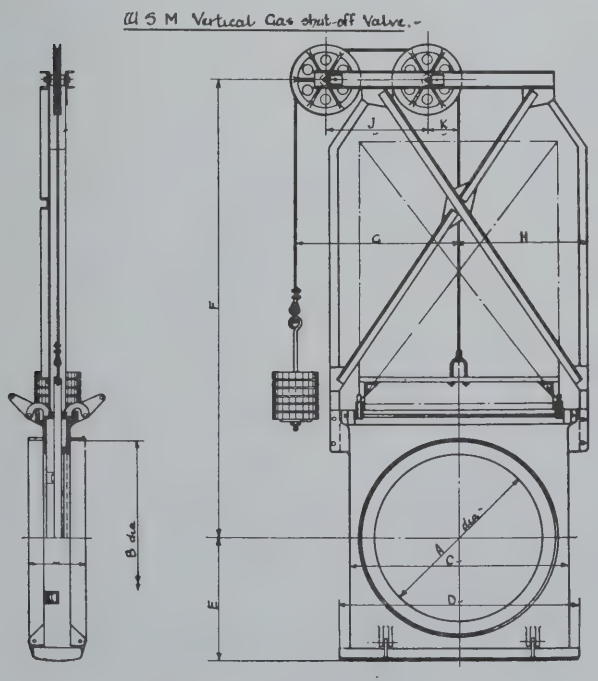


FIG. 6.

therefrom, before admitting gas to the furnace; this reduces the possibility of explosions to a minimum.

Isolating the producers.

It is very necessary to have facilities for isolating each gas producer from the hot gas main, and the best type of valve for this purpose is either the mushroom valve or disc valve. Fig. 5 shows a mushroom valve operated by screwed spindle and hand-wheel. This method of operation is better than the rope-suspended balanced valve, as it enables the operator to screw the valve tightly down on to its seat when closing. By way of further example may be mentioned the Wellman vertical damper or disc valve (Fig. 6), which consists of a steel reinforced asbestos plate, sliding between two castings with machined face on gas main side. The asbestos plate is wedged

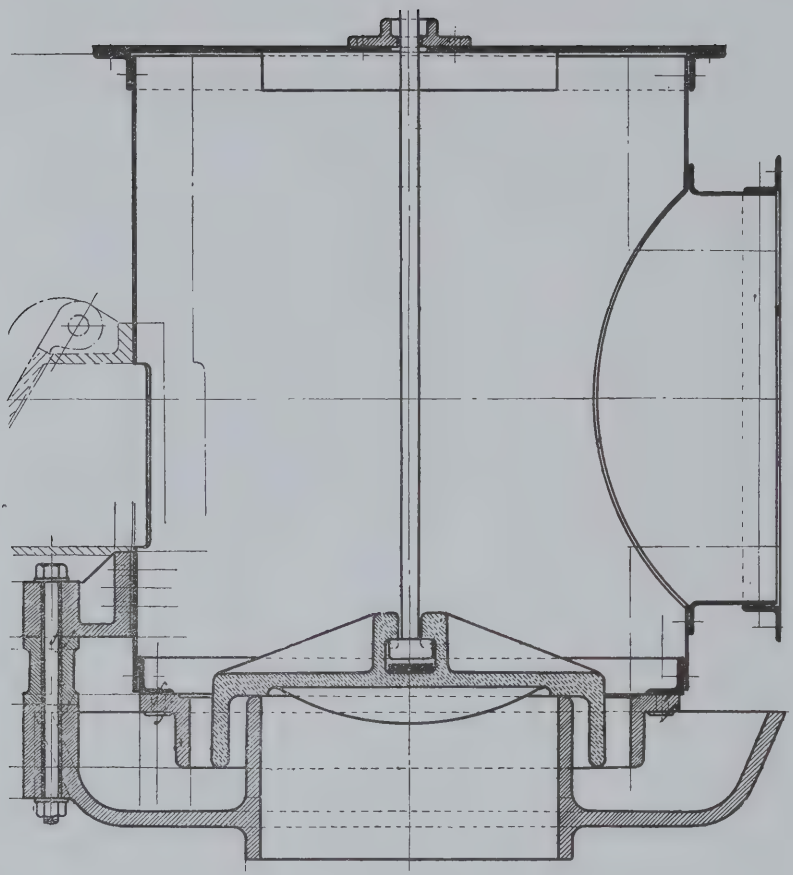


Fig. 7.

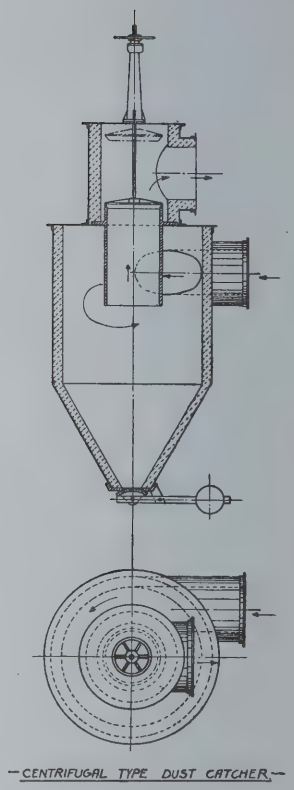


Fig. 8.

tightly against this machined face, thus forming a gas-tight joint. Fig. 7 shows a water-sealed shut-off valve.

Dust separation.

To separate dust and soot from the gas as far as possible before it enters the hot gas main, dust-catchers of various designs and sizes have been adopted, all of which aim at either reducing the velocity of the gas, impinging it against baffles or changing its direction.

A circular dust-catcher, wherein all the above principles are incorporated to a certain extent, is shown in Fig. 8.

Fig. 9 shows a combined dust-catcher and hydraulic shut-off valve. When gas is shut off water is up to the level shown forming a seal, and to admit passage of the gas the water is run off through the sluice valve. The great thing to bear in mind in designing gas connections between producers and the hot gas main is to avoid long horizontal tubes in which dust, etc., can be deposited, as these are very difficult to keep clear.

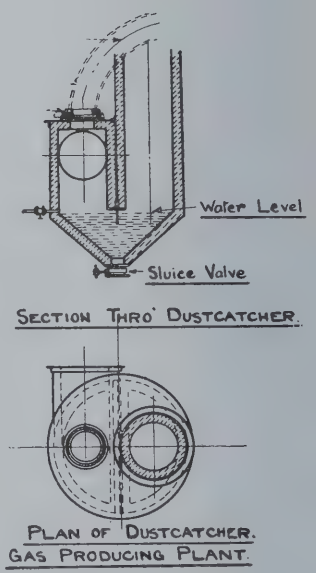


Fig. 9.

Furnace valves.

The gas is usually delivered to the furnace through a mushroom valve similar to the isolating valve (Fig. 5) illustrated previously, and then in the case of the reversing regenerative type of furnace, through a

gas reversing valve. Fig. 10 shows one type of the well-known Forter valve, which is largely adopted in this and other countries. It consists of an outer casing, a base casting with three ports, a hood to connect two ports and the operating mechanism. The centre port is connected to the chimney. Waste gases from the furnace flow from whichever outside port the hood is covering to the chimney port. This leaves a clear passage for the gas or the air entering the casing through the mushroom valve at the top, to pass through the third port to the furnace or regenerator. Reversal of the flow of gas or air is accomplished by moving the hood to a position over the centre port and the one previously uncovered.

The base of the valve is a cast-iron rectangular pan, with three walled openings or ports. The hood, which covers the centre and one end port, is semi-elliptic in form, and consists of a heavy steel casting or mild steel casing having a cross bar tying the side-walls together, as well as pockets to engage the supporting lever. This construction does not require brick lining. The base pan holds a quantity of water, so that when the hood is over the ports, a water seal is formed to prevent the escape of gas. The base pan has a tapped hole at each end for a water pipe. There is a perforated strainer at the intake end and a dam plate at the other end to hold the water at such a level as to allow the hood to extend three inches into the water, forming a seal.

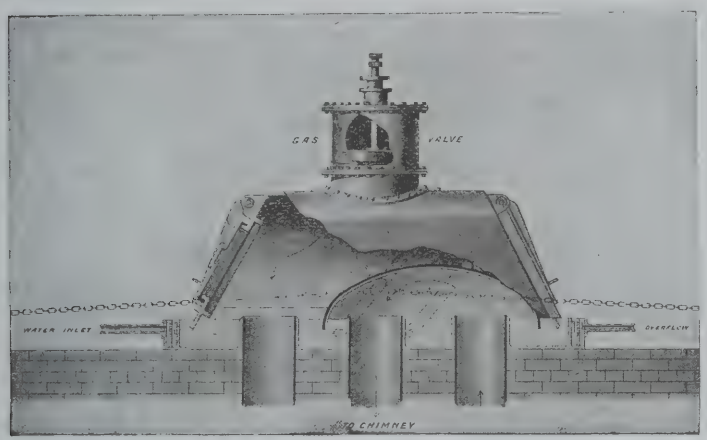


FIG. 10.—*The Forter Valve.*

The outer casing is made of steel plate and should be lined with firebrick, if producer gas is used. It has cast-iron door frames and a door at each end through which the hood may be removed or inserted. Each door has a small peep hole with a swinging cover which enables inspection at any time.

On the top of the casing is a cast-iron neck, which connects either with the fuel gas flue or the air intake, depending upon the purpose for which the valve is used. The hood is moved by a series of levers and coupling shafts, which extend through the water under the casing and into sockets on the hood. The shafts move on chilled iron bearings. At each side of the valve is a counterweight attached to an arm and sector, over which passes a chain connecting with the supports of the hood. The form of this sector is such that the counter weights balance the weight of the hood at any position. As mentioned in foregoing, the perfect balance of the valve enables it to be hand-operated, but where desired hydraulic, pneumatic or electric operating gear may be used.

Amongst other types of gas reversing valves in general use are the "Dyblie" and "Lake," both of which give satisfactory service.

Chapter 5.

GAS CLEANING AND BY-PRODUCT PLANT.

By H. C. RICKWOOD.

So far consideration has been given to the production of gas which is used in its hot crude state. There are many cases, however, such as gas engine operation, distribution through long or small mains or, in fact, in any case where the dust and impurities in the gas would interfere with efficient operation where such gas cannot be used. Moreover the gas may be heavily laden with moisture, which if the gas were burnt in its crude state would result in a lower heat generation in a furnace than if the moisture is previously

condensed out. Further, the gas may contain valuable by-products, which it is profitable to recover. For these reasons it is necessary that the plant should be designed for supplying cool clean gas. Such plants may be broadly divided into two classes: (*a*) Plants in which the recovery of tar and ammonia is provided for; (*b*) plants in which no by-products are recovered.

(A.) BY-PRODUCTS AND THEIR RECOVERY.

The by-products obtainable from the gasification of bituminous fuels are ammonia and tar. Benzol is only present in producer gas in very small percentages, its recovery thus being impracticable. The most important by-product is ammonia, the yield of which of course varies very considerably according to the nature of the fuel. This ammonia is obtained entirely from the nitrogen in the fuel, and although numerous efforts have been made to obtain it in the producer, also from the nitrogen in the air blast, no success has yet attended these efforts.

It is obvious, therefore, that the economic aspect of an ammonia recovery scheme is controlled mainly by the nitrogen content of the fuel and the market value of the recovered ammonia. So far as this country is concerned, the only suitable fuel, from the by-product point of view, is bituminous coal. British bituminous fuels have a nitrogen content ranging from about 1.0 to 1.5 per cent. by weight on the dry fuel, representing 27.2 to 40.8 lbs. of ammonia per ton of dry fuel. This ammonia is usually recovered as sulphate, and the above figures represent 111 to 167 lbs. of sulphate of a purity of 24.5 per cent. NH_3 per ton of fuel. The efficiency of recovery in general practice, however, does not exceed 60 per cent. to 70 per cent.; consequently the limits of practical recovery lie between 66 and 115 lbs. of ammonium sulphate per ton of fuel gasified.

Dealing with the other by-product—tar—considerable progress has been made of recent years, notably with regard to the quality of the tar produced. Years ago, when the old Mond process was being exploited, the tar was of a very poor quality, and only in special cases did it pay to go to the expense of specially treating or distilling it. As a rule, however, the tar was considered more of a nuisance than otherwise, and was very difficult to dispose of. Improvements in the process during the last few years have been directed to, and resulted in, a very great improvement in the quality of this by-product, and in general characteristics the tar produced on a modern plant approaches that produced by low-temperature carbonisation, and after simple preliminary treatment it has a good market value.

The by-product recovery producer.

The producer designed for use in by-product recovery work differs in certain essential details from other types.

The controlling factors in the formation of ammonia in a gas producer are: (1) Temperature of fuel bed; (2) quantity of steam supplied; (3) time of contact of gas and fuel, fuel depth; (4) gradual cooling of the gases containing ammonia as they ascend from the ammonia formation zone to the outlet; (5) nature of the fuel and the state of the nitrogen contained therein, as well as the maintenance of a constantly solid fuel bed—free from blow holes which can overheat and dissociate the ammonia.

Regarding the first four points, which are to a large extent interdependent, experiments by various authorities show that the best temperature for the formation of ammonia is in the neighbourhood of 800° to 900° C., whilst at higher temperatures the ammonia appears to be again decomposed. For this reason it is necessary to keep the temperature of the fuel bed above the actual combustion zone below the limits named. In the old Mond process this was accomplished by introducing a very large quantity of steam with the air blast, amounting to about $2\frac{1}{2}$ lbs. per lb. of fuel gasified. In that process the gas containing the ammonia was submitted to a certain cooling effect by passing through a superimposed layer of green fuel, the fuel bed having a total depth of about 7 feet above the grate. Investigations conducted in 1907 by Messrs. Bone and Wheeler showed that the maximum percentage of nitrogen was recovered as NH_3 under these conditions. Later research, however, has shown that the steam factor is not so important as had seemed to be the case in earlier years. A factor of equal if not greater importance is the rapid cooling of the gas after the formation of the ammonia, and this end has been achieved of recent years in two ways:—

(*a*) In the Moore process by cooling the gas producer sides by means of a water jacket. This producer is elliptical in cross section, such design having been devised to enable the cooling effect to penetrate to the centre of the fuel bed. The heat absorbed by the water permits of a considerable reduction in the steam requirements, though the desired effect is only partially achieved owing to the fact that the cooling by the water jacket in reality only penetrates a few inches into the incandescent fuel. This producer is not designed with a view to tar recovery.

(*b*) In the Power-Gas Corporation's process, which is designed for both ammonia and tar recovery, the cooling is effected by the fuel itself, the depth of the fuel bed being considerably increased beyond that employed in the old Mond process, the gases thus being gradually cooled while remaining in prolonged contact with the fuel. In this process each particle of fuel is submitted to a slow and uniform heating up, distillation and gasification, which results in a much reduced tendency to clinker, and almost entirely eliminates poking. The steam consumption is very considerably lower, being about 50 per cent. of that used in the old Mond process.

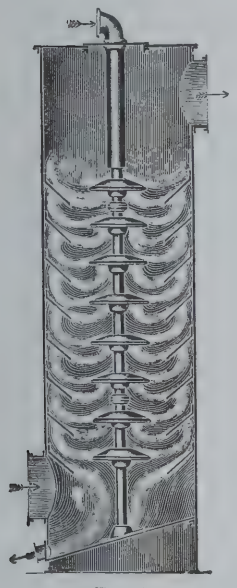


Fig. 1.
Lymn Gas Washer.

In both the Moore and the Power-Gas process the temperature of the gas leaving the producer is much reduced, being as a rule well below 300° C. Obviously this latter feature, as well as the considerable reduction in steam consumption, enables decided economies to be effected both in capital and running costs, whilst the ammonia recovery is very little affected.

Regarding point 5, the nitrogen content of fuels generally varies from something like .2 per cent. in certain woods up to as much as 3 per cent. in peat—as pointed out above, it is 1.0 to 1.5 per cent. in bituminous coals. The state in which the nitrogen exists in the fuel is of considerable importance in determining the possible efficiencies of recovery of nitrogen as ammonia. At present insufficient is known regarding the chemical structure of a fuel, and it is therefore impossible to determine from analysis alone what percentage of the nitrogen is recoverable as ammonia. It is beyond the scope of this work to study the question in detail, and reference may be made to a work such as "Modern Gas Producers," by N. E. Rambush, where it is more fully discussed.

Until lately in Great Britain the recovery of ammonia has been the paramount consideration in the design of by-product recovery producers, the tar being of quite secondary importance. On the other hand, on the Continent and especially in Germany, greater attention has been devoted to the recovery of tar as a by-product, which fact of late years also applies to this country. This line of development was the natural outcome of the pressing need in Germany during the war for the largest possible supplies of tar oils, and this end was sought from both the distillation and the gasification processes. Also the competition of synthetic ammonia was felt there earlier than here. This, however, is now upon us in Great Britain, and also the large amount of tar being used for roads has rendered the latter of considerably more importance than formerly.

The best-known producer plants in this country for the recovery of ammonia and tar are the Mond and the later Lymn types, followed by the modern developments of the Power-Gas Corporation. The essential features of the last-mentioned producer may be briefly summarised as follow:—

It is specially designed for so-called low-temperature gasification, is circular in cross section, and the main body of it is parallel except the upper zone, which is tapered. The total fuel depth in this producer may reach or even exceed 14 feet. The grate may be either of the static or mechanical type, the latter for fuels having a high ash content. There is no water cooling, the whole casing being lined with firebrick. A central gas offtake bell is provided at the top of the fuel bed, and is so designed that the flow of gas upwardly through the fuel is uniformly distributed over the whole cross section. By this means a uniform low-temperature distillation of the fuel is effected before the gasification zone is reached, and the gas leaves the producer at a relatively low temperature (150° to 300° C.). The air supply is not superheated as was the case in earlier plants, and is saturated by steam to about 75° to 80° C. according to the fuel used.

Recovery of ammonia.

Regarding the plant for the recovery of the ammonia from the gas and the general after treatment of the gas, we shall describe that manufactured by the Power-Gas Corporation as being typical of modern practice. Indeed, this happens to be at the present time the only plant being exploited in this country for the manufacture of sulphate of ammonia and low-temperature tar from producer gas.

On leaving the producer the gas passes through a dust catcher on its way to the gas washer, where it meets a descending column of water, and is cooled to about 80° to 85° C., the bulk of its dust content being removed in this vessel. From the washer the gas is led through the ammonia absorber, where it comes into intimate contact with a solution of sulphate of ammonia containing a very small percentage of free sulphuric acid which absorbs the ammonia from the gas. The gas passes thence through a final gas washer and cooler where the temperature is reduced to about 30° C. by further contact with water. The vessels used in this plant both for the absorption of the ammonia and the general cleaning of the gas are the static Lymn washers (Fig. 1), each consisting of a vertical cylindrical shell with a central shaft on which are fixed at suitable intervals shallow cones or distributors. Alternating with these cones, and attached to the shell, are inverted truncated cones which serve as collectors. By this arrangement the gas is in each vessel brought into oft repeated intimate contact with a thin film of water, the momentum of the gas itself breaking up this film over and over again into a fine spray. The subsequent treatment of the gas depends upon the purpose for which it is to be used; if for gas engines or other purposes requiring a high degree of cleanliness it is conducted first through two cleaners of the centrifugal type, and finally through dry scrubbers packed with sawdust and shavings. Where this high degree of cleanliness is not required, however, the dry scrubbers may be omitted. The air for the producers is blown through an air saturator constructed on the same principle as the gas washer described above, where it meets the water which has been heated by cooling the gas in the gas washer. The gas cooling and air saturation thus forms an operating cycle.

The ammonium sulphate liquor is kept in circulation until the requisite strength has been reached (about 1.18 to 1.2 specific gravity), after which it is passed to a storage tank, from which it is supplied as required to a vacuum evaporator, where the bulk of the water is evaporated off and the sulphate of ammonia salt crystallised out. The salt is finally dried in a centrifugal hydro extractor and passed to the store for packing.

The process here described is a direct development of that devised by Dr. Mond in 1885, but is much simplified both as regards construction and operation.

Work has also been done in the direction of recovering the ammonia as liquor instead of as sulphate. The chief difficulty here is that on account of the relatively large volume of gas, the ammonia has a very low concentration, and since the extraction of this ammonia by water is dependent on the partial pressure of the ammonia in the gas, which will of course also be low, a low absorption efficiency is the result. Other problems arise due to the presence in the producer gas of gases other than ammonia, notably carbon dioxide, but, it is understood, that these have lately been solved, and this process is now in successful operation.

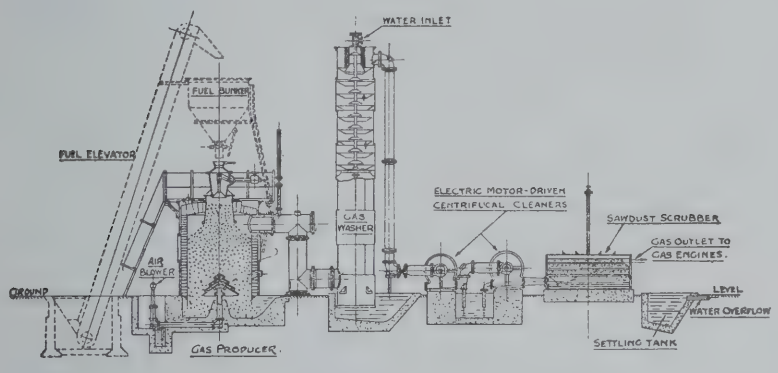
Other processes have been devised, mainly on the Continent, for the recovery of the ammonia through the agency of the sulphur in the coal, calcium sulphate, etc., but they are not used at present in connection with gas producers.

Recovery of tar.

Regarding the recovery of tar as a by-product, many processes have been devised for its extraction from the gas, and it is not possible in a work of this class to describe them in any detail. In general water is the washing medium, and after circulation in the various vessels on the plant the water used for this purpose is allowed to settle in large tanks where the tar separates out either at the top or bottom, some tar being heavier and some lighter than water. In the majority of plants centrifugal action in conjunction with water is employed for the final cleaning or recovery of tar, in which stage the lighter oils are brought down. In an efficient tar recovery installation the final tar content leaving the centrifugal cleaners should not exceed .25 to .5 grammes per cubic metre of gas.

After settlement the tar may be dehydrated by centrifugal machines, such as made, for example, by the Sharples Company. In such a machine tar containing 35 per cent. of moisture can be brought down to 1 to 2 per cent. in a very short time. In Germany many plants employ a disintegrator in which the gas is washed with hot tar. This naturally does away with the necessity for subsequent dehydration.

The only other by-product which has engaged the attention of gas engineers is sulphur. This exists in the gas in the form of hydrogen sulphide, about half of the sulphur in the fuel being converted. Three processes may be mentioned for the removal of this hydrogen sulphide from the gas, viz.: (1) Dry purification by bog iron ore—this being the process employed in nearly all lighting gas works; (2) wet purification by ferric hydroxide; (3) processes for the combined removal of ammonia and hydrogen sulphide, of which several have been developed.



DIAGRAMMATIC ELEVATION OF NON-RECOVERY PRODUCER GAS PLANT FOR POWER PURPOSES

FIG. 2.

Up to the present, however, no very satisfactory results have accrued from any of these processes as applied to producer gas. In certain cases, however, it may be desirable to bring down the sulphur content as low as possible on account of its deleterious properties for the work which the gas has to perform. In such cases the first of the above-mentioned processes is usually employed. Otherwise it does not pay to treat the gas for recovery of this by-product.

The following figures, typical of results obtained on a modern by-product recovery plant such as has been described, will be of interest:—

FUEL ANALYSIS.	Moisture	5.7 per cent.	
	Ash	8.0 do.	on dry fuel.
	Volatile matter	31.2 do.	
	Total carbon	71.1 do.	
	Fixed carbon	56.6 do.	
	Hydrogen	5.0 do.	
	Nitrogen	1.47 do.	
	Nett calorific value B.Th.U.'s per lb.	12,150	
GAS ANALYSIS.	CO_2	8.3 per cent.	
	CO	21.0 do.	
	H_2	20.5 do.	
	CH_4	4.9 do.	
	N_2	45.3 do.	
	B.Th.U.'s nett cu. ft.	178	
	Gas efficiency $\frac{\text{Cal val. of gas}}{\text{Cal. val. of coal}}$	80 per cent.	
	Average gas yield (cubic feet) per ton of dry fuel gasified	122,000	
	Average ammonium sulphate yield per ton of dry fuel gasified	90 lbs.	
Average yield of dry tar per ton of dry fuel gasified		21 galls.	
Steam into producer per lb. of dry fuel		1 lb.	

(B.) NON-BY-PRODUCT RECOVERY PLANTS.

For this class of plant nearly every type of producer which has hitherto been described may be utilised, but in general a producer of the non-mechanical or semi-mechanical type is employed except with certain special fuels.

A typical plant for producing gas sufficiently clean for use in gas engines is shown in Fig. 2.

The gas leaving the producer enters the gas washer, which, in the case under consideration, serves the dual purpose of washing the dust out of the gas and cooling the gas. Hence the lower cones and discs are inclined at a rather steeper angle than are the upper ones, in order to ensure that the dust collecting on the cones and discs shall be properly washed off. In this vessel the bulk of the dust is extracted from the gas and the major part of the cooling is effected. The subsequent cooling and cleaning comprises two centrifugal cleaners and the dry scrubbers charged with shavings and sawdust. It will be seen that this part of the plant is in general similar to the cleaning portion of a by-product recovery plant.

In a plant of this type a certain amount of tar is recoverable as a by-product, but for the maximum production of good quality tar a producer on similar lines to that described for the recovery of ammonia, incorporating an upper distillation zone, is essential.

A special development of the non-recovery producer plant will be of interest in its application to the firing of coke ovens and gas works' retorts or ovens. The advantage of this method of firing the ovens or retorts is of national importance. In the case of coke ovens it will leave the whole of the coke oven gas free for distribution purposes, and in the case of gas works, bearing in mind the fact that very poor quality coke may readily be gasified in the producers, it will set free large quantities of good quality coke which would otherwise be consumed. The fuel in use here will probably, but not necessarily, be the coke made in the ovens or retorts, and under certain conditions may, as stated, be of a very poor quality. Hence the plant has to be designed to meet these conditions.

In order to avoid excessive clinker formation contingent on the use of such a fuel and the correspondingly heavy labour involved in its removal, a water jacket has been fitted to producers employed for such fuels. This jacket has the effect of cooling the fuel bed and of maintaining it at a temperature too low for the formation of clinker at or near the periphery. At the same time, however, the gas quality is to a certain extent detrimentally affected by this chilling action. As an alternative the water jacket may form part of a steam-raising system in cases where the steam can be usefully employed on the works. The following description is of a plant equipped with such a steam-raising jacket and designed to deliver gas to the retort settings at a temperature of less than 30° C.

The producer is of the semi-mechanical type, being fitted with rotating ash pan and mechanical grate. The steel shell is in two sections, the lower of which is the water-filled boiler jacket which may extend to about the middle of the fuel bed or rather higher. The upper part of the shell is brick-lined in the usual way, the inside diameter of the brick lining being the same as that of the jacketed portion. The jacket is connected top and bottom with a vertical waste heat boiler adjacent to the producer.

The hot gas from the producer enters the top of the waste heat boiler and passes downward through a series of tubes, and imparts the bulk of its heat to the water which has already been heated in the producer jacket. In this way about 2 lbs. of steam at a working pressure of 100 to 120 lbs. per sq. in. may be generated per lb. of coke gasified. This steam is available for use in the steam turbines driving the blower and gas cleaning fan, as well as other power purposes. A suitable quantity of steam will be by-passed from the turbines at a pressure of 10/15 lbs. per sq. in. for steaming the chambers, and for saturating the blast to the producers. Where steam drive is employed for the grate the exhaust from this will also be available for the producers.

After passing through the waste heat boiler the gas is led through a washer of a type already described and finally through a centrifugal gas cleaner.

For the purpose of retort heating it is necessary that the gas be reasonably cleaned and free from dust in order to avoid blockage of the distribution pipes, and the periodic rebuilding of the settings consequent upon the accumulation of dust in the flues. Moreover, the dust may have a deleterious effect on the flue lining itself.

AUXILIARY MACHINERY.

The remarks already made on this subject in connection with producers in general need some amplification in their bearing on the by-product recovery plant as well as to the clean gas plant without such recovery.

The type of blower available is somewhat restricted, as the third type referred to, viz., the steam jet blower is not suitable for by-product recovery plants, although it may be employed on some of the smaller plants for producing clean gas.

The blower usually employed to-day is either the steam turbo blower (Class 1) or the electrically-driven centrifugal fan. In view of the fact that steam is required in the producer which may be at a low pressure, the former is to be preferred as the steam can be exhausted into the blast main. This type of blower, whether steam or electric driven, is easily controlled in accordance with the demand for gas. Automatic control may be accomplished by means of a small governor of the floating bell type installed on the outlet of the plant, after the centrifugal cleaners. This governor responds immediately to fluctuations in the gas pressure, and the rise and fall of the bell is employed to control either the steam valve to the blower or a valve on the air main by-passing some of the blast to atmosphere. Alternatively, where electric drive is employed for the blower the governor may vary the resistance of the field. A more positive method of control involves the use of two governors, one in the air main leaving the blowers and one in the gas main, leaving the gas cleaning fans.

The air pressure governor is operated by means of the gas pressure (or vacuum as the case may be) existing in the common main leaving the producers, the governor being fixed near the blowers (e.g., suspended from the machinery house roof) and operates by means of the rise or fall of the bell, a butterfly valve in the air main. The gas pressure governor, which is of similar construction, controls a butterfly valve in the gas main, leaving the gas cleaning fans. The bell in this case is actuated by the pressure existing at or near the point of application of the gas.

Valves. The valves employed on the type of plant under consideration are somewhat different from those used on a hot gas plant. Where a battery of producers is in question, which is usually the case in a by-product plant, a producer may require to be isolated from the remainder of the plant for some long period, and under these circumstances the sliding plate or quadrant type of valve is usually more satisfactory than the mushroom or disc valve commonly employed on hot gas producers. The valve consists essentially of a plate which may be either of the sliding or quadrant shape, working between two castings, a tight joint being secured by asbestos rope packed into a groove in each casting and bearing on the two sides of the plate. Moreover, as these valves may be left in the open or closed position for considerable periods and as they are liable to accumulate tar and dust from the gas it is necessary to make some special provision to overcome the sticking which must inevitably occur under these conditions. This is attained by fixing straining bolts to the two castings in such a way that they may be forced apart, leaving the plate reasonably free to move. This movement may be effected by hand, or in the case of larger sizes by means of a chain and chain wheel working in conjunction with a rack and pinion.

On the cooler gas mains, as well as on the blast mains, valves of the sluice or rack and pinion type are entirely satisfactory. They are not, however, suitable where great heat may cause distortion, or for dirty gas where tar or dust may accumulate and prevent the tight closing of the valves.

Pumps. These are required for circulating the water (or sulphate liquor) through the washer ammonia absorber and cooler. These are usually of the centrifugal or turbine type, driven by direct-coupled electric motor. In the case of the ammonia absorber all parts of the pump which come in contact with the liquor should be acid resisting. Piston pumps are unsuitable here on account of the presence of tar in the liquors and circulating water.

Fuel Handling. For large plants it is usual to erect a coal storage bunker over the producers capable of holding several hours' supply of coal according to local conditions. The coal is elevated to this bunker by one of the many types of fuel elevating plant on the market; amongst these may be mentioned the bucket type elevator and band on push plate conveyor, the gravity bucket elevator and conveyor, hoist with small tip wagons, etc.

Motive Power. In addition to the blowers and pumps, power is required at the following points:—(1) Grate where mechanical ash removal is employed—this may be by simple steam cylinder (the steam being available for saturating the blast) or motor; (2) centrifugal cleaners, usually direct-coupled motors; (3) tar separators, usually steam-driven self-contained; (4) centrifugal hydro-extractor, usually direct or belt-coupled motor; (5) fuel handling.

Thermometers and Pressure Gauges. These have already been discussed in connection with hot-gas producers and gas machines. In large by-products plants it is usual to fit both thermometer and pressure gauges at several points on the plant, so that observation can be kept over conditions prevailing at the inlet and outlet of the various vessels. By this means it is easy to locate conditions giving rise to irregular working; indeed, it is common practice to collect all the pressure gauges on one gauge board, which is located in the machinery house.

APPLICATIONS OF BY-PRODUCT GAS.

Power. The application of by-product gas, and indeed on a much smaller scale, of non-recovery gas, to the generation of power may be conveniently divided into the following classes:—(1) Gas producer plant combined with reciprocating gas engines; (2) gas producer plant combined with steam boilers and steam turbines (or reciprocating engines), (*a*) the steam used entirely for power purposes and to its fullest extent; (*b*) the steam used simultaneously for process work and power; (3) gas producer plant combined with internal combustion turbines.

Class 1 needs no description. It has been employed in the past on a considerable scale and with considerable success. The reciprocating gas engine, however, does not now appeal seriously to many large power-station engineers and is too cumbersome for large scale power production. Moreover, the capital outlay is very high.

Class 2 is, however, deserving of very careful consideration, as representing a development of the last few years. Until comparatively recently it has been considered uneconomical in most industrial regions to utilise a gas specially manufactured from coal or other fuel for firing boilers of steam plant, but the great advances and economies which are shown in the gas plant developments already described in combination with modern specially-designed gas-fired boilers have resulted in a combined thermal efficiency which is little short of those obtainable in the best direct coal-fired steam stations. Hand in hand with the advances in the producer gas plant, great improvements have been achieved in the matter of gas-fired boilers specially constructed for efficient gas firing. Gas-fired boilers of all sizes up to 36,000 lbs. steam, from and at 212° F. per hour in a single drum, can now be obtained with a guaranteed 85 per cent. efficiency, and even 90 per cent. with air preheated, while the gas plant has an efficiency of 78 to 80 per cent. when by-product recovery is included, and 90 per cent. without by-product recovery. In the by-product recovery case, it should be pointed out that 10 per cent. of the carbon is yielded in the form of recovered tar and oils, the mentioned 80 per cent. being the gas thermal efficiency. The boilers available for this highly efficient gas firing are mainly of the multi-firetube type, and probably the best known is the Spencer-Bonecourt "Kirke" patent boiler. The patentees specially point out that the gas is burnt in individual tubes by a special multiple-jet burner arrangement of high combustion efficiency. The absence of large combustion chambers cuts out all potential risk of explosion, and furthermore there is no brickwork of any sort required by these boilers, consequently no leaky settings, as each boiler is an entirely self-contained unit standing in its own cradle. Induced draft equipment is provided and high gas velocities are worked to, with corresponding high evaporations per unit of heating surface.

It is claimed that gas is burnt with practically theoretical air volumes, the spent combustion gases leaving the boiler tubes at only a few degrees higher temperature than the steam. The superheater sections are generally similar to the boilers, and overall efficiencies of 85 per cent. gas to steam are guaranteed on these plants under ordinary running conditions, this guarantee figure being increased to 90 per cent. if air preheaters are added to utilise the waste gases leaving the fans, no economisers being required under these circumstances. A further means of obtaining high gas thermal efficiencies with steam boilers not expressly designed for gas firing is to use one of the special burners for which practically perfect combustion is claimed. Such burners have given high thermal efficiencies and could be

advantageously used in those cases where boilers already exist and a small loss in thermal efficiency is of less importance than extra capital outlay. The use of the produced steam in efficient turbines requires no comment.

Section (*a*) of this class refers to power stations in which the steam is used to its fullest extent by means of efficient condensation.

Section (*b*), however, is on quite another plane. It does not have reference to ordinary power stations at all, but is applicable to those many instances where private undertakings, such as paper mills or chemical works, require not only considerable power for the operation of their plant, but also a large amount of steam for their processes.

It is highly economical to deliver the steam at high pressure into an extraction, pass-out or bleeder turbine discharging the whole or part of its steam at low pressure for process purposes, that part not so discharged being condensed in the ordinary way. Class 3 brings into consideration a new prime mover, viz., the internal combustion gas turbine.

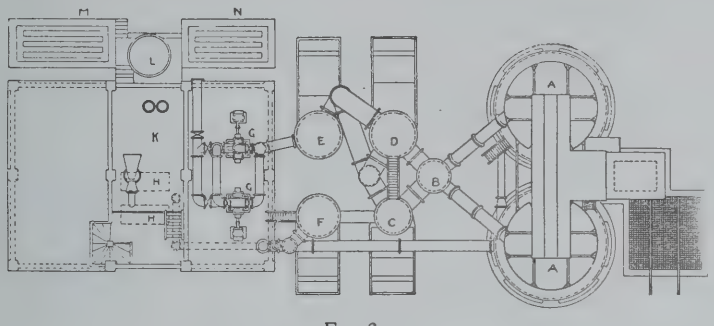


FIG. 3.

As such a turbine has been made already in large units up to 5,000 kw. and in the future may be efficiently applied to commercial purposes, a brief description follows of the Holzwarth type of this new prime mover.

Gas and compressed air are forced into each explosion chamber of a series to a pressure of about 40 lbs. to 50 lbs./sq. in. above atm. at a temperature of about 2,000° F. While this mixture is still in eddying motion it is ignited by means of high-tension igniting plugs.

The combustion of the mixture takes place on the pure explosion principle, the whole mixture being burnt before the nozzle valve is opened. When the combustion is complete, a pressure of about 250 lbs./sq. in. above atm. is reached at a temperature of about 2,500° F. At the moment of maximum pressure the nozzle valve is rapidly opened to its full extent by means of the initial explosion pressures, and the expansion period begins. The gases expand through de-Laval nozzles at a temperature of about 1,250° F. They impinge upon the vanes of a two-blade running wheel and leave the gas turbine by the exhaust pipe connecting with the waste-heat boiler plant.

This explosion and expansion cycle and impulse to the turbine wheel only last about two-tenths of a second. As soon as expansion is finished, air is scavenged through the explosion chamber, nozzle valve and nozzles, whereby the remainder of the explosion gases are swept out of the chamber and the ducts leading to the nozzles, all of which are thereby simultaneously cooled.

The explosion chambers are operated in rhythmical succession, so that the resultant gases impinge consecutively upon the running wheel. As a matter of fact, although the materials of the turbine nozzles are momentarily subjected to high temperatures, the average temperature is only 750° F. or 400° C., i.e., no higher than that of the superheated steam used in modern steam turbine practice. Therefore, contrary to general ideas on this subject, the Holzwarth gas turbine has no more arduous conditions to withstand than many modern steam turbines, so that fears in regard to durability of material become groundless.

A by-product recovery plant suitable for use in connection with either section of Class 2 is shown in plan view in Fig. 3, where A-A are two gas producers with overhead coal storage bunkers. B is a dust-catcher through which the gas passes on its way to the gas washer C. The gas passes thence through the ammonia absorber D and the final gas washer E to the two centrifugal gas cleaners G, and from these it is taken direct to the boilers. F is the air saturator, H-H are two electric-driven turbo-blowers; K is the ammonia sulphate house, where the sulphate liquor is evaporated and finally bagged for sale. N is a tar sump where the tar from the whole plant is collected, and from which it is pumped to an overhead

tar tank L and thence to a centrifugal tar dehydrator. The dehydrated tar is then ready for sale and is collected in the sump M.

For use in connection with Class 1 or 3 dry scrubbers would be added after the gas cleaners G.

Economic aspect.

In order to provide some guidance as to the economic aspect of the modern by-product recovery gas producer plant working in conjunction with boilers and steam turbines as covered in Class 2a previously described, the following table has been prepared showing the estimated operating costs of such plant in comparison with those of a straight modern coal-fired steam turbo station and with a similar station operating on powdered fuel.

ANNUAL OPERATING COSTS.

	1		2		3	
	40 per cent. Load.	70 per cent. Load.	40 per cent. Load.	70 per cent. Load.	40 per cent. Load.	70 per cent. Load.
Installed Capacity... ...	25,000 kw	25,000 kw	25,000 kw	25,000 kw	25,000 kw	25,000 kw
Full Load	20,000 kw	20,000 kw	20,000 kw	20,000 kw	20,000 kw	20,000 kw
Capital Cost—						
Plant	£319,000	£319,000	£240,000	£240,000	£236,000	£236,000
Foundations, Bldgs., etc.	48,150	48,150	71,250	71,250	71,250	71,250
Total Capital Cost... ...	£367,150	£367,150	£311,250	£311,250	£307,250	£307,250
Cost per installed kw. capacity	£14.7	£14.7	£12.45	£12.45	£12.3	£12.3
Annual Debit—	£	£	£	£	£	£
Fuel	67,850	118,700	58,200	101,850	45,800	80,300
Labour	15,965	15,965	6,570	6,570	6,570	6,570
Management	1,000	1,000	500	500	500	500
Repairs, Stores, Light, etc.	12,030	15,975	9,300	12,450	7,670	10,800
Sulphuric Acid	6,990	12,200	—	—	—	—
Depreciation—						
Plant	31,900	31,900	24,000	24,000	23,600	23,600
Foundations, Bldgs., etc.	2,889	2,889	4,275	4,275	4,275	4,275
	138,624	198,629	102,845	149,645	88,415	126,045
Annual Credit—						
Sulphate of Ammonia ...	19,600	34,200				
Tar Oils	22,600	39,500				
	42,200	73,700				
Total Annual Cost ...	£96,424	£124,929	£102,845	£149,645	£88,415	£126,045
Total kw./h. generated ...	70,080,000	122,640,000	70,080,000	122,640,000	70,080,000	122,640,000
Cost per kw./h.	0.33d.	0.245d.	0.35d.	0.293d.	0.303d.	0.247d.

For the first of these two cases, as well as for the gas producer combination, fuel has been taken at 20/- per ton, whilst for the powdered fuel installation a price of 17/- per ton has been taken in conjunction with a lower calorific value. It is unnecessary to enlarge further on the figures given, as they are self explanatory.

COMPARISON OF CAPITAL AND OPERATING COSTS OF POWER GENERATION.

The installation comprises:—

(1) By-product recovery gas producer plant, gas-fired boilers and steam turbo generators.
(2) Water-tube boilers fitted with mechanical stokers and steam turbo generators.
(3) Water-tube boilers with pulverised fuel equipment and steam turbo generators.

GENERAL CONDITIONS.

Alternatively (*a*) 40 per cent. load and (*b*) 70 per cent. load for 24 hours daily and 365 days per annum.

Fuel used—for 1 and 2, bituminous coal having a calorific value of 11,400 B.Th.U. nett per lb. dry fuel, and costing 20/- per ton containing 5 per cent. moisture; for 3, rough Midland slack having a calorific value of 10,000 B.Th.U. nett and costing 17/- per ton.

Overall heat consumption of steam turbo generators with direct coal firing, 18,000 B.Th.U. per kw./h. at full load.

Overall heat consumption of combined gas producer plant and steam turbo generator, 23,500 B.Th.U. per kw./h. at full load.

BY-PRODUCTS.

Sulphate of ammonia, 85 lbs. per ton of dry fuel, value £8 per ton.
Dry tar, 21 gallons per ton of dry fuel, value 4d. per gallon.
Sulphuric acid (140° Tw.), £3 per ton.

LABOUR.

Unskilled, 1/- per hour (8-hour shifts).
Skilled, 1/3 per hour (8-hour shifts).
Charge hands, £5 per week.

PART VII.—INTERIOR HEATING.

By Margaret Fishenden, D.Sc., F.Inst.P.

Chapter 1. .

HEAT REQUIREMENTS.

The needs of man for artificial heat are largely what he happens to have made them. They vary not only with his surroundings, but also with his habits and the stage of progress he has reached. Irrespective of race, climate, or occupation, however, it is essential that the human body should be kept warm ; existence itself demands the maintenance of a nearly uniform internal body temperature of about 98° F.

Food may be regarded as the fuel which feeds the body furnace, and provides the energy necessary both for warmth and physical or mental action. Combustion, however, is neither direct nor local, but occurs throughout the mass of the living cells of the body substance itself, particularly in the muscles. These are stimulated by mechanical work, a cold environment, or ample food, but their activity has a very definite upper limit, beyond which "further increase of work ceases even in the presence of direst necessity ; and this is also the case with the heat production, even though it were very necessary, and we were likely to freeze."*

The muscles of the heart and respiratory organs are always at work, and even when resting in warm surroundings the heat production of the body never ceases entirely ; but it reaches a minimum value—usually known as the "basal metabolism"—which is approximately proportional to the body surface area, and equal to about 275 B.Th.U.'s per hour for an average man. This is not sufficient to maintain a normal body temperature except in a warm environment. In cold weather warmth must be sustained either by muscular action, which accelerates the rate of internal heat production, or by artificial control of the environment. The conditions of modern life have forced the latter method upon all civilised communities.

Although the artificial heat requirements of savage or nomad races are very meagre in relation to the needs of more highly civilised peoples, the demands of most industrial countries are approximately similar. The idle classes or those engaged in sedentary occupations need more heat than the vigorous manual worker ; but all stages of society are accustomed to have their dwellings warmed in cold weather, much of their food cooked, and water heated both for personal and domestic use. Interiors must also be kept reasonably warm and dry to prevent the deterioration of fabrics and furniture, though this is in general quite a secondary aim, the primary object being the comfort of occupants. [1 to 10.]

Definition of comfortable conditions.

During recent years a considerable amount of experimental work has been undertaken not only with the object of defining the various combinations of air temperature, air movement, humidity, radiating surfaces, etc., which induce a suitable rate of cooling for any specified occupation, but also with a view to formulating optimum conditions of comfort in any case. There is a good deal of difference of opinion on the matter, since both the personal element and questions of acclimatisation are more or less involved.

In America a wet-bulb temperature of 56° F. has been laid down by the Society of Heating and Ventilating Engineers as the standard for sedentary workers in still air, whatever the degree of saturation. This corresponds with dry-bulb temperatures ranging from 56° F. at 100 per cent. saturation to over 75° F. at 25 per cent. saturation. The writer, however, does not believe it to be a true criterion of comfort, since it exaggerates the effect of vapour pressure upon the comfort of sedentary workers in cool surroundings, where evaporation is a relatively unimportant means of heat loss. In this connection

* Voit, "Munchener medizinische Wochenschrift," 1902, xlix., 233.

attention may be drawn to a statement of O. W. Griffiths, to the effect that "changes in the humidity at ordinary cool room temperatures are immaterial, at least so far as *heat losses* are concerned. Convection, even that which is set up by the body alone, completely swamps the effects."* There is little doubt, at any rate in this country, that saturated air at 56° F. would be found far too cold for inactive occupations; and that 75° F. even at 25 per cent. of saturation would be considered too warm.

The writer has shown, as indeed may be concluded from ordinary observation, that for continued sedentary work an environmental temperature of about 64° F. is required in this country, whatever the humidity, over a range varying from 40 to 60 per cent. of saturation. Corresponding values obtained by E. V. Hill vary from 70½° F. to 63½° F., or a mean of 67° F., while Shepherd's figures range from 68½° F. to 64½° F., or a mean of 66½° F. [15]

For the present purpose, namely that of comparing different methods of heating rather than of arriving at precise definitions of comfortable conditions, the exact standard adopted is not of primary importance, provided that the same standard is always adhered to. An environment at 64° F. with still air, or its equivalent as nearly as can be determined, will therefore be assumed suitably warm for long periods of sedentary work, although for short periods somewhat cooler conditions may suffice. It happens that in surroundings at 64° F. the radiation and convection losses from the body are about equal, and are both nearly proportional to the temperature difference, the former between clothing surfaces and surrounding surfaces, the latter between clothing surfaces and surrounding air. Hence for every degree the temperature of surrounding surfaces rises, the air temperature may be dropped by about a degree without any appreciable modification of sensations of warmth. Similarly, for every degree the temperature of surrounding surfaces falls, the air temperature must be increased by about a degree in compensation.

In the presence of small surfaces at very high temperatures, such as open fires, the general room temperature may be lower without discomfort by an amount which depends upon the intensity of the radiation absorbed. The writer found that a mean horizontal component of radiation equivalent to about 30 B.Th.U. per square foot per hour across the position of an occupant was sufficient to keep him comfortably warm in an environment otherwise at 60° F. In surroundings at 55° F., 50° F. and 45° F. it was found necessary to increase this to 75 B.Th.U., 120 B.Th.U. and 170 B.Th.U. respectively for the retention of equivalent warmth conditions, but these values must be taken as approximate only. The most comfortable combination was found to be air at 55° F., with such radiation as was sufficient to preserve due warmth. This probably exemplifies the ideal to be aimed at with open fire heating; for air temperatures exceeding say 60° F., although not high enough to maintain warmth without a fire or other radiator, tend to induce slight mental lassitude; while, on the other hand, in rooms below about 50° F. the familiar "scorched on one side, chilly on the other" sensation associated with open fire heating in cold weather begins to be noticeable. Sensations of comfort, however, are doubtless dependent upon the degree to which the source of heat is localised. With an extended, and correspondingly less fierce, source, much lower air temperatures might be expected to prove both comfortable and healthy, but, as will appear later, they are not altogether easy to realise in practice.

Since the convection loss from warm bodies is accelerated by air movement, draughts occasion the necessity for higher room temperatures or increased radiation. In currents of 2, 4 and 6 feet per second enveloping the whole body, the writer has shown that temperatures respectively about 4, 6 and 9 degrees in excess of those needed in still air become requisite; this is in agreement with the American standards. Such high rates of air movement, however, for obvious reasons are not to be recommended, except as a possible means of ameliorating unavoidable high temperatures.

Muscular exertion increases the rate of body heat production to an extent which is governed almost solely by the intensity of effort, but which may double or treble the heat output associated with quietude. The mechanical efficiency of the human machine has been shown by many investigators to be only about 20 per cent., the remaining 80 per cent. of the energy expended appearing in the tissues of the body as

*See "The Science of Ventilation and Open Air Treatment," Part I., p. 100. Medical Research Committee, Special Report Series, No. 32, 1919.

heat, which must be got rid of by the usual channels. Hence a much cooler environment is desirable for heavy muscular work than for sedentary occupations. In many cases it is not feasible to decrease the temperature of workrooms sufficiently for the increased radiation and convection to counter-balance the intensified heat production; hence breathing is quickened and sweating induced, evaporation becoming an increasingly important means of heat removal as the work becomes heavier or the environment becomes warmer. It is thus advantageous that the vapour pressure of the air should be kept low and its movement increased, so that both convection and evaporation losses may be accelerated.

In the present state of knowledge optimum comfort conditions are not specifically definable, but the most important condition undoubtedly appears to be the adjustment of the environment so that the heat generated in the body may always be dissipated without undue strain upon natural thermostatic controls. Too uniform conditions, however, seem to be undesirable. In general, relatively low air temperatures, say not exceeding 55° F. to 60° F.; with moderate humidity, say 30 per cent. to 70 per cent. saturation; ample air changes without excessive draught and radiation, either from an extended source or from an open fire; are to be preferred to a uniform environment of 64° F. [11 to 18.]

Chemical purity of room air.

It has for many years been customary to determine the adequacy of air interchange in rooms by reference to the proportion of carbon dioxide present, the Departmental Committee on Ventilation in Factories and Workshops having recommended in 1902 that the amount should not be allowed to exceed 12 parts per 10,000 of air in the daytime, or 20 parts when gas is used for illuminating purposes.

The importance of ventilation in keeping down the concentration of carbon dioxide in a room is no longer recognised. It has been amply demonstrated that this gas is harmless in itself, even when present in relatively high concentration, although its measurement may afford a useful indication of the rate of air change. The primary functions of ventilation are to maintain a suitable rate of body cooling and to minimise the risks of infection by preventing an accumulation of harmful bacteria; thus, even at fairly low temperatures, a certain minimum rate of air movement is probably desirable. A standard of six complete changes per hour, distributed as evenly as possible throughout the room, has been suggested by the Home Office as a minimum in factories and workshops. This is far more than is usually either necessary or customary in dwelling houses. [19 and 20.]

Mode of action of artificial heating.

It has been remarked that the impression of warmth associated with any interior depends mainly upon the temperatures of air and surrounding objects, including the boundary surfaces of the room; although in extreme cases humidity and air movement may become of importance. Likewise all methods of artificial heating consist essentially in the introduction into a room either of warm air or of warm surfaces; while means of controlling the humidity and air movement may be included. When air is employed as the heating medium, contact with it gradually raises the temperature of the walls, furniture, etc., to a level which is determined not only by the temperature volume and distribution of the air introduced and the period of heating, but also by the construction, furnishing, and exposure, of the room, and the prevailing weather.

Heated surfaces, on the other hand, when brought into a room, not only warm the air directly by conduction and subsequent convection, but also form sources of radiation which bring about air heating as a secondary effect. The air does not itself absorb radiant energy to any appreciable extent, but absorption of radiation leads to a gradual warming of the contents of the room which then communicate heat to the neighbouring air. In certain cases, such as that of an open fire burning below a flue, the heated air is carried away at once to the outside; and the heating effect produced in the room is due, in the first instance, almost solely to radiation. Whatever the proportions of primary radiation and air heating, however, the ultimate effect is the warming of furniture, walls, and air. So soon as these reach temperatures

in excess of the exterior surroundings of the room, heat begins to escape both by conduction through the building fabric and in the warm air which flows away through chimney flues, ventilators, open doors or windows, etc.

This constitutes a steady drain upon the heat supply, and if the interior temperature is to be maintained heat sufficient to counter-balance the losses to the outside must constantly be supplied; but the quantity of energy required for this purpose will vary widely with the nature and position of the structure, and with the outside weather conditions. Since it is essential for reasons of hygiene that ample ventilation should be assured, the heat involved in its upkeep may be regarded as an unavoidable expenditure. It is thus generally in the direction of reduced conduction losses that a saving in the heat requirements of a building is to be looked for. The fuel bill, whatever the system of heating adopted, will be closely associated with the type of structure, and it is clear that in the interests of fuel economy building materials and building methods should be chosen with a view to providing the best insulation feasible. [21]

Insulating value of building materials.

The selection of building materials is rendered difficult by the fact that the rate at which heat passes through a partition, such for instance as the wall of a room, is governed not only by its intrinsic conductivity, but also by the temperatures which its inner and outer surfaces attain, which are dependent upon the nature of the material as well as upon the conditions to which it is exposed. The heat transferred through a wall must first be communicated by convection and radiation to the inner surface; then, after passing by conduction through the mass of the material, it is dissipated from the outer surface to the outer surroundings, again both by convection and radiation. When a steady rate has been attained, it is obvious that the rates of heat transmission to the inner surface, through the material, and from the outer surface, must all be equal, and it is customary to write :—

$$Q = \alpha_i\,(t_i - T_i) = \frac{k}{d}(T_i - T_o) = \alpha_o\,(T_o - t_o),$$ whence on eliminating T_i and T_o :

$$Q = \frac{(t_i - t_o)}{\frac{1}{\alpha_i} + \frac{1}{\alpha_o} + \frac{d}{k}}$$

where Q is the rate of heat transfer per unit area, t_i, t_o, the temperatures of inside and outside surroundings, T_i, T_o, inner and outer surface temperatures, k the absolute conductivity of the material, d its thickness and α_i, α_o, inside and outside coefficients of surface heat transfer. For thick partitions of insulating material, $\frac{d}{k}$ may be large compared with $\left(\frac{1}{\alpha_i} + \frac{1}{\alpha_o}\right)$, and the rate of heat transmission will then be governed mainly by the absolute conductivity of the material. For thin partitions of conducting material, $\frac{d}{k}$ may be small compared with $\left(\frac{1}{\alpha_i} + \frac{1}{\alpha_o}\right)$, and the rate of heat transmission will then be governed mainly by the surface transfer. For this reason, a sheet of thin paper, although its absolute conductivity is very low, transmits more heat than a sheet of polished metal of the same thickness. The above expression is clearly only an approximation, since α_i and α_o depend upon both radiation and convection, neither of which is proportional to the temperature difference. Again, the temperature of surrounding objects may be widely different from that of the surrounding air. This would tend to diminish slightly the leakage of heat from a building surrounded by other warmed buildings; and may, on the other hand, enormously increase it on clear nights, when the effective temperature of the sky is often much lower than the outside air temperature. Further, until a body becomes very hot, the radiation emitted by it at any specified temperature is practically independent of its colour, from glossy white to dead black, but is greatly reduced by a bright metallic coating. Above a certain temperature, on the other hand, the emission of radiation begins to bear a marked relation to colour, being less for white or light surfaces than for dark colours. Similarly the radiation which differently coloured surfaces absorb from moderately warm

bodies to which they are exposed does not vary with the colour of the surface; but the rate at which they absorb heat from very hot sources, such for instance as the sun, is much greater for dark than for light colours, and is again least for brightly polished metallic surfaces. Hence, in computing the conduction losses through any building material, its surface properties as well as its absolute conductivity must be taken into account.

Any alteration in the surface heat transmission tends to cause such a re-adjustment of surface temperatures as will re-establish equilibrium between the rates of heat transmitted to the inner and from the outer surfaces, and through the thickness of a material. Thus, either increase in conductivity, reduction in thickness, or acceleration of the outer surface transmission of heat, will tend to lower the inside surface temperature; while decrease in conductivity, addition to thickness, or retardation of the outer surface transfer of heat, will tend to raise the inside surface temperature. With both outer and inner surroundings at 64° F., for instance, the inner surface of either a 9in. brick wall or a single glass window would obviously be also at 64° F., and no heat would be transmitted. But with an outside temperature of 40° F., the inside wall surface would tend to attain 58° F., the window 53° F.; while with the outside surroundings reduced still further to 20° F., these would tend to become 54° F., and 43° F. respectively. In actual rooms the conditions are too complicated to allow of exact determinations of the various inner surface temperatures attained; but in cold weather these may be much lower where the insulation is poor. This point is of great significance in the heating of rooms. It shows that the colder the weather, or the worse the insulation of a room, the higher will be the air temperatures required in order to compensate for the reduced surface temperatures; and indicates how unsatisfactory is air temperature alone as a criterion of comfort. It explains also why reasonably good insulation is essential in very cold climates, not only in order to keep down conduction losses, but also to prevent the inner surfaces from reaching so low a level that uncomfortably high air temperatures are needed to sustain warmth. [21-26.]

Proportions of heat used for different purposes.

Sufficient has been said to show how closely heat requirements are bound up with methods and materials of construction and with weather conditions. Further, very different environments are suitable for different occupations. The quantities of heat needed in a room cannot therefore be defined exactly, but there is little doubt that the greater proportion of the fuel consumed for domestic purposes is used either directly or indirectly for interior heating.

Hot water requirements, however, are nowadays very high, and probably exceed 5 gallons per head daily. Estimates, variously arrived at, suggest that as much as 50 per cent. of the total domestic coal is consumed in appliances designed to produce hot water, although most of these also provide facilities for warming the kitchen, cooking, etc. The average efficiency of hot water production probably does not exceed 10 per cent.; but even in the most efficient domestic independent boilers the heating of such large quantities as are used would entail an aggregate consumption of at least 4 million tons of coal or coke annually. A considerable quantity of additional fuel would also be necessary in the kitchen for cooking and warming purposes.

The amount of fuel used for cooking operations is small compared with that expended in room warming and hot water production, in spite of the fact that the process is generally very inefficient thermally. Kitchen ranges are usually designed both to cook and produce hot water, and also to warm the room in winter. If cooking alone were required even coal-fired kitchens could be run on a fraction of the present fuel consumption. [27.]

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Chapter 2.

METHODS AND MECHANISM OF HEATING.

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It has already been shown that there are two fundamentally different methods of heating a room. Either a source of radiation may be introduced (radiation heating), or a circulation of warm air may be maintained (convection heating). In practice, the division between these is not sharply defined, since all heating appliances give rise to both radiation and convection, though in widely varying proportions, depending not only upon their temperature, but also upon their shape, size, position, surface treatment, etc.

The radiation from non-incandescent bodies, or from bodies at relatively low temperatures, is often wrongly assumed to be less important than the heat imparted to the surrounding air. Quite the reverse is in fact true. All ordinary surfaces whatever their colour, unless of small dimensions, when freely exposed give a high proportion of radiation even at temperatures only a few degrees in excess of their surroundings. The net radiation emission may be calculated in B.Th.U. per square foot per hour from the expression $16\ E \times 10^{-10}\ (T^4 - t^4)$, where T is the temperature of the surface, t that of the surroundings and E the emissivity, which is equal to 1 for a theoretical " perfectly black " body and, for temperatures below red heat, to about 0.9 for most surfaces other than metallic ones. Convection in the still air of a room is given by $C\ (T-t)^{\frac{5}{4}}$ B.Th.U. per square foot per hour where C has been shown by Griffiths and Davis to be equal to 0.30 for a vertical plane surface or for vertical cylinders of more than 8 inches in diameter, provided that the height is not less than about 15 inches. For smaller dimensions the coefficient increases. For large horizontal surfaces facing upwards C becomes 0.38; for surfaces facing downwards, 0.20.

As the temperature rises the amounts of heat emitted by radiation and convection both increase, at first at about the same rate; but after a few hundred degrees is reached, the radiation increases more rapidly, until ultimately it approaches 100 per cent. of the aggregate energy emission.

The rates at which a large freely exposed vertical surface (a) with a perfectly black finish, or in other words, with the maximum possible emissivity, (b) of 50 per cent. emissivity, loses heat by radiation and convection respectively, in surroundings uniformly at 60° F., are given in Table I. For a horizontal surface facing upwards convection is increased by about 27 per cent.; for a horizontal surface facing downwards it is decreased by about 33 per cent., radiation undergoing no change. The heat transmission to a vertical surface at 60° F. from its warmer surroundings, may also be estimated from Table I. The heat transfer to a horizontal surface facing upwards will be the same as that from a horizontal surface facing downwards; the transfer to a horizontal surface facing downwards the same as that from a horizontal surface facing upwards.

When, however, a surface is not freely exposed, as in the case of a warmed ceiling, convection currents may be largely checked, since the air which becomes warmed by contact with the heated surface is already at the highest level attainable in the room. Similar considerations apply to the case of a floor at a lower temperature than the air above it. Non-uniformity of temperature, however, may cause local circulation.

It will be seen from the table that at 100° F. energy is lost by the black surface at the rate of 70 B.Th.U. per square foot per hour, 57 per cent. of this appearing as radiation, 43 per cent. being spent in direct air heating. At 1,000° F. the total energy emission has risen to nearly 9,000 B.Th.U. per square foot per hour, of which radiation accounts for 82 per cent., convection for 18 per cent. At this temperature even a surface of only 50 per cent. black body emissivity in an environment at 60° F. loses 70 per cent. of its heat as radiation.

It frequently happens that the surfaces of heating appliances are not so spread out as to allow of radiation from every part penetrating freely into a room. On the other hand, the air can as a rule circulate over the entire surface. Hence the area which is effective as an air heater may be much greater than that which is effective as a radiator. This is generally so both with open fires and sectional radiators. Nevertheless, in the former case, since the air which becomes warmed through contact with the hot fuel

rises up the flue and does not take any direct part in the warming of the room, the useful heating effect is restricted almost exclusively to radiation; and the thermal efficiency, calculated in terms of the proportion of the heat of the fuel utilised in the room, is low. Were the fire burning without a flue there would be in addition to radiation a considerable amount of direct air heating, with a corresponding increase in efficiency. In the latter case, not on account of the lower temperatures operating but because of the screening effect of adjacent columns of the radiator upon one another, the effect is due in the main to air heating. There is, however, no loss of radiation in the sense that convection is lost from open fires, since radiation between re-entrant surfaces is re-absorbed by the radiator, and the whole of the energy the latter emits becomes available in the room. But there are of course heat losses at the boiler furnace.

In the case of a freely exposed wall maintained at about the same temperature as hot water radiators, radiation and convection would contribute about equally to the energy emission; while, as already stated, from a warm ceiling radiation may become by far the more important means of heat transfer. The energy emitted from closed stoves is again divided about equally between radiation and convection, but in the case of such extended sources the radiation is more uniformly distributed and less intense locally than that from open fires.

TABLE I.

Temperature of Surface °F.	Heat loss in B.Th.U.'s per sq. foot, per hour, from a Vertical surface in surroundings at 60° F.							
	(a) Perfectly black.				(b) Of 50 per cent. emissivity.			
	Radiation.	Convection.	Total.	Radiation as % of total.	Radiation.	Convection.	Total.	Radiation as % of total.
100	40	30	70	57	20	30	50	40
200	186	144	320	56	93	144	237	39
300	415	284	699	59	208	284	492	42
400	756	436	1,192	63	378	436	814	46
500	1,240	605	1,845	67	620	605	1,225	51
1,000	7,110	1,560	8,670	82	3,550	1,560	5,110	70
1,500	23,500	2,660	26,160	90	11,750	2,660	14,410	81
2,000	58,200	3,860	62,060	94	29,100	3,860	32,960	88

The essential dissimilarity between air heating and radiation heating is a great stumbling block to any exact comparisons of methods which fall into different classes; for while with air heating all parts of a room are nearly equally comfortable, except perhaps near a window, with radiation heating comfort depends largely upon proximity to the source of heat, especially if this consists of a small area at a very high temperature. In other words, with convection heating, the air throughout a room, even though the latter may be large and have only a single occupant, must be brought to a more or less uniform temperature; but with radiation heating, a small fire, which produces comfortable conditions only over a very restricted area, and which would be altogether inadequate to warm the whole room, may suffice for a limited number of occupants, provided they can get near enough to it.

The most important differences between different types of heating appliances may be summarised briefly as (1) the thermal efficiency of the system as measured by the proportion of the potential energy of the fuel consumed which becomes available for useful heating purposes; (2) the proportions in which this energy appears as radiation or convection; (3) the distribution and intensity of the heating effect; (4) the ventilation which is induced; (5) the adaptability of the heating, or the rapidity with which it comes

into full action; (6) the cost of the fuel in relation to its potential heat value; (7) the quantity of energy, in terms of initial coal consumption, required to perform any specified service.

In a temperate climate such as that of Great Britain, heating and ventilating problems bear little relation to those in places where low winter temperatures are experienced, such for instance as Canada or the Northern United States, where the open fire as a means of heating in winter would be quite inadequate, and where the admission of cold air for ventilating purposes directly from the outside is impracticable. In this country the open fire is the recognised method of house heating. Other methods are looked upon as innovations. For offices and large buildings generally, the difficulty of distributing evenly the radiation from open fires, and the work associated with their upkeep, has compelled the adoption of central heating, usually by means of hot water. But few consider it either so healthy or so pleasant as open fires.

The open fire.

The open coal fire is a true radiation heater. A gradual warming of the room is induced as a secondary effect, but owing to the high rates of air interchange, which normally vary from some 5,000 to 30,000 cubic feet an hour, according to the design of grate and flue and the conditions of burning, the temperatures reached are usually not high enough for comfort, except in positions where the direct warming effect of the fire can be felt. The operation of such fires is analogous to that of the sun; and just as sunshine may provide ample warmth on a cold, still day, so in the glow of an open fire one may remain comfortable in a room which would at once feel cold if the fire were screened or put out.

It must not, however, be supposed that the total energy of combustion of the coal is expended usefully in radiation. Imperfect combustion indicated by smoke and soot, as well as the escape of invisible unburned or partly burned gaseous products, reduces the heat available for the warming of the room. The actual magnitude of this loss is somewhat uncertain; doubtless it is closely associated with the conditions under which combustion occurs; but that it should be reduced to a minimum is a primary condition of efficiency. Cohen and Russell[2] found in the chimney gases from house fires an average soot content amounting to $6\frac{1}{2}$ per cent. by weight of the coal used. More recently Sinnatt[3] has detected also both carbon monoxide and unsaturated hydrocarbons; soot alone represented a loss of only 2 per cent., but the total loss due to incomplete combustion was over 20 per cent. This work is being continued in greater detail. So high a leakage of unburned products had not previously been suspected, but figures such as the above emphasize the importance of determining the conditions of maximum chemical efficiency, both in the interests of fuel economy and clean air. It then remains to direct into the room in the form of radiation, suitably distributed, the highest possible proportion of the heat generated. This is largely a matter of correct grate design. The whole extent of the incandescent fuel should be visible from the most extended area of the room possible; and it is obvious that effective insulation against conduction losses through the back and sides of the grate, and through the hearth, should be provided.

Coal or carbon probably conforms closely to "black body" laws. Hence a very large, single piece of glowing coal with linear dimensions of the order, say, of a foot, if suspended freely in surroundings at ordinary temperatures, might be expected to yield radiation equivalent to as much as 80 or 90 per cent. of its aggregate energy emission. But since, as we have seen, convection after a certain point begins to increase with diminution in size, a lump of coal of more normal magnitude would give a smaller proportion of radiation. In fires where many lumps of varying size are heaped up together, the conditions become too complicated to allow of even an approximate theoretical estimate of the allocation of radiation and convection; direct experimental investigation must thus be relied upon.

By surrounding fires contained in a round wire basket with a ring-shaped calorimeter, Peclet[4] many years ago found that the radiation from burning coal or charcoal was equivalent to 50 per cent. of the calorific value. Such a high efficiency is not obtainable from ordinary grates against walls, where some of the radiation is directed up the flue, and where heat is also lost by conduction. For ordinary sitting-room grates, the radiation efficiency has been found experimentally to range from about 15 to 25 per cent.[5]

As would be anticipated, the effect of recessing a grate in its setting, as in the case of dog grates, or of bringing the canopy too far over the firebed, is to intercept radiation which would otherwise find its way into the room, and thus to diminish the efficiency. Building up a fire so high in the grate that the top of the fuel approaches the bottom of the canopy has a similar effect, owing to increased radiation losses up the flue. The presence of a boiler behind an open grate, or imperfect insulation, also reduces the useful radiation per lb. of coal burned. Again, generally speaking, grates which are very deep from back to front are relatively inefficient, but are improved by sloping forward the back over the firebed, as is now the usual custom. A slight advantage is also to be gained by slanting the sides of a grate inwards towards the back.[6] The radiation efficiency of coal fires in ordinary commercial grates, however, seldom deviates far from 20 per cent. But an additional 10 per cent. of the heat of the coal may be transmitted to the room by conduction through the fire wall.

The distribution of radiation varies with the design of a grate; and since horizontal radiation, or radiation thrown only slightly upwards or downwards, is generally more useful than radiation directed above the heads of the occupants of a room, or down on to the hearth, distribution should be taken into account in comparisons of the behaviour of different grates. As would be expected, vertical fronted grates direct a relatively greater proportion of radiation downwards, and less upwards, than modern barless grates in which the surface of the fuel is more nearly horizontal. Whether this is an advantage or a disadvantage depends largely upon the height of the firebed above the hearth. Use is sometimes made of bright metallic surfaces to reflect radiation falling upon the hearth or grate surroundings back into the room.

At the same distance from a fire, the intensity of radiation is naturally less towards the sides than directly opposite the centre. Except for minor differences due to asymmetry of burning, the rate of diminution to one side is the same as to the other, and for grates of moderate size usually follows nearly a cosine law. For bow-fronted grates the distribution may be more uniform. The intensity of radiation also obviously decreases steadily with increase in the distance from the fire, although, calculated in terms of the average horizontal component from floor level to, say, 4 or 5 feet height, which is roughly what the occupants intercept, the rate of decrease is considerably less rapid than would be given by an inverse square law. There are zones of comfort around open fires, in any part of which the radiation received is sufficient to ensure proper warmth at the prevailing room temperature. Outside these zones, it is too warm on the side near the fire, too cold on the side remote from the fire. As the day goes on, and the room gradually gets warmer, the zones of comfort not only recede from the fire but also increase considerably in area unless the rate of combustion is cut down. Similarly, for a given room temperature, they increase in width and recede from the fire as the rate of combustion increases.[7]

When a gas fire is lighted, the radiation from it rapidly increases to a practically uniform value. No such steady conditions can be obtained with coal fires, in which the rate of burning is continually varying. When fresh coal is thrown upon the embers in a grate it chills and obstructs the glowing fuel. Radiation is therefore temporarily decreased, but as the coal gradually becomes warmed and finally ignites, it increases to a maximum which usually corresponds with the period of maximum flame. Subsequently, as the flames die down and the coal burns away, the intensity of radiation diminishes again. The marked effect of flame is to be explained by the rapidity with which the volatile constituents of the coal are consumed, especially when the draught is high, the gaseous products of some coals representing 30 per cent. or more of their total calorific value.

The very gradual rise in temperature which an open fire produces in a room is one of its most serious drawbacks, for it is precisely in the period immediately following kindling, when the room as a whole is still cold, that a maximum intensity of radiation is required for comfort. Actually, at this stage the fire is yielding a minimum of radiation.

Very high rates of ventilation, usually averaging from 5,000 to 30,000 cubic feet per hour, according to the conditions, are associated with open coal fires.[5] The instantaneous rate of flow, like the radiation emission, is continually varying, according to the rate of burning; it obviously depends also upon the resistance in the circuit and may be considerably modified by the opening or shutting of a door or window or the manipulation of a damper. But in general excess air and products of combustion carry a large

proportion of the heat generated by the coal up the flue. For high rates of air flow this may reach as much as 50 per cent., but it is reduced by diminution of draught. It must be borne in mind, however, that this heat is not in any case entirely wasted, since it serves to warm slightly upper rooms adjacent to the flue, and keeps warm the wall above the fireplace. For flues built on inner walls, indeed, it is reasonable to assume that the true heat losses associated with open fires are limited to the sensible heat of the gases leaving the chimney and the loss in unburned products.

Diminution in draught, although it reduces the proportion of the calorific value of the coal escaping up the flue as sensible heat, is apparently not usually accompanied by a corresponding increase in radiation efficiency.[5] The exact reason for this is not clear, since information on several points, such as the relation between the rate of burning and the chemical efficiency of combustion, is lacking. It is necessary, in any case, to distinguish between a reduction in draught effected by increasing the resistance to the passage of air through the fire itself, and a reduction effected by increasing the resistance in the flue throat. As a rule, a large proportion of the air is drawn directly into the flue; hence, by pushing in the canopy above a fire, the total air flow can be reduced considerably without any commensurate effect upon the rate of burning. As a result, the temperatures, both in the flue and in the room, may go up. On the other hand, the rapidity of combustion can be controlled directly by adjustment of inlets drawing air actually through the fuel bed, without diminishing greatly the total air flow. In this case, the temperatures both in the flue and in the room may go down. But in either case the conduction losses per lb. of coal burned will be increased.

Reduced draught, however, although it may not increase the actual radiation efficiency, allows of fuel economy, since it is associated with higher room temperatures, in conjunction with which a lessened intensity of radiation suffices for comfort. The popularity of the modern barless grate is doubtless to be attributed to this cause, and to the slow, steady combustion effected.

In spite of its many obvious disadvantages, there are real grounds for our national love of the open coal fire, which is a method of heating in many ways well adapted to the climate. Its variable effect, although often accounted a fault, is considered by physiologists to be stimulating. The high rate of ventilation which it can maintain is also an advantage, but, as has been stated, entails an increased fuel consumption. When once they have burned up, open fires are fairly flexible, provided that the draught control is satisfactory.

Coke in open grates.

Gas coke, if reasonably dry and not containing too much ash, gives a higher radiation efficiency and a more uniform heating effect than coal in open grates. But it is more difficult to light, and will not burn up well, unless the draught through the fire is high or the insulation of the grate good. For this reason, attempts are being made to develop commercially low-temperature carbonisation processes, for the production of a free-burning, but smokeless, solid fuel.[8]

The writer found that a dry gas coke of calorific value 12,900 B.Th.U.'s per lb., containing 10 per cent. of ash, gave a radiation efficiency of 28.5 per cent. of its theoretical heat value, compared with 24.5 per cent. for a high-grade bituminous coal of calorific value 14,500 B.Th.U.'s, and only 3 or 4 per cent. of ash. In a different grate, the corresponding values were 24.5 and 21 per cent. respectively.[9]

Several low-temperature cokes, low in ash, and of calorific value 13,200 B.Th.U.'s per lb., gave when dry radiation efficiencies varying from 30 to 34 per cent., compared with 24½ per cent. for coal. Again, the values in three different grates for low-temperature cokes with 10 per cent. ash and calorific value 12,300 B.Th.U.'s per lb., were (a) low-temperature coke 31 per cent., coal 24½ per cent.; (b) low-temperature coke 24 per cent., coal 19½ per cent.; and (c) low-temperature coke 20 per cent., coal 17½ per cent.[10]

Bligh and Hodsman have shown recently that the radiation efficiency of coke is closely associated with its ash content. Thus two cokes, both nearly dry, but with 5½ and 1½ per cent. of ash, respectively gave values of 25 and 29 per cent., compared with 20 per cent. for a coal of calorific value 12,500 containing 9 per cent. of moisture. By treating coke with sodium carbonate, its ignitability and combustibility were greatly increased, but the radiation efficiency was somewhat decreased.[11]

Many grates have been designed specially for use with coke; these usually rely for success upon a deep column of fuel, good draught control, or effective insulation.[12-14]

Anthracite will burn satisfactorily in some open grates, although a good supply of wood is necessary to start it. The radiation efficiency is a few per cent. above that for coal.

Gas fires.

The action of gas fires is essentially similar to that of open coal or coke fires, and their heating effect in a room is restricted mainly to radiation, the hot gases and products of combustion passing away up the flue. Since the radiation from non-luminous flames is comparatively low, the flame is utilised to raise to incandescence hollow, vertical, refractory columns, known as "radiants." In this way, by narrowing the depth of fires from back to front, suitably adjusting the size of flames and radiants, and paying careful attention both to the design and the material of the latter, the radiation efficiency of modern gas fires has been brought to about 40 to 50 per cent. of the heat value of the gas burned. Such a good result is, of course, contingent upon fires being of correct design and used to the best advantage. It does not depend upon the rate of ventilation unless the distance between the top of the radiants and the bottom of the canopy is small, when high rates of air flow may slightly diminish the efficiency.[15-20]

The essential parts of an up-to-date gas fire are the burner, with its gas and air regulator; the radiants; the canopy; and the flue outlet. The latter remove completely the products of combustion of the gas, and create ventilation comparable with that obtained from open coal or coke fires. To obtain the best efficiency the gas must be burned at a proper rate; hence the introduction of gas and air regulators, which ensure a suitable consumption and adequate aeration, and the production of clean, hot flames of suitable height.

If properly fitted and intelligently used, well-designed gas fires should be free from either noise or smell and should give ample ventilation for any normal requirements. The fact remains, however, that many people find them less comfortable than coal fires. Whether this is due to their uniformity, or to the fact that they are generally used intermittently and thus have not time to produce any very considerable general heating of a room, or to some other reason, remains to be proved.

Closed stoves.

The radiation from solid fuel fires in closed stoves is intercepted by the stove casings, which themselves become hot and produce both radiation and air heating. If the surfaces are freely exposed, and there is no special provision for air circulation, the proportions of energy emitted as radiation and direct air heating are about equal; but the radiation, unlike that from open fires, is from a comparatively large area at a temperature only a few hundred degrees in excess of its surroundings. Hence the zone of comfort is extended, especially as the general heating of the room is considerable. The energy spent in radiation and air heating together, by a stove in the middle of a room, must be nearly equal to the difference between the theoretical heat value of the fuel and the sum of the heat value of unburned products and sensible heat in the flue gases at ceiling level. Since in closed stoves a much greater proportion of the air passes through the fuel bed than in the case of open grates, the air inlet below the grate is so adjusted as to reduce considerably the volume entering; otherwise the rate of combustion would become excessive. Hence the flue loss in sensible heat is usually low. The loss due to products escaping unburned is not accurately known, but by analogy with the results from various types of furnaces it is probable that overall efficiencies of 75 or 80 per cent. may sometimes be attained in a room from a central stove with metal flue pipe; or, in a building, from any closed stove with inner flue, provided the combustion is fairly complete. For stoves built against outer walls, there will be additional losses, due to conduction with a corresponding reduction in efficiency.

Flueless gas stoves.

A greatly increased return can be obtained from gas fires by dispensing with a flue. In this case, the products of combustion are discharged into the room, and the sensible heat previously carried up

the flue becomes available for air heating. Hence, if the combustion is complete, the overall efficiency is 100 per cent. of the theoretical heat value of the gas. Of this, especially in stoves with an open fire or incandescent mantle such as the condensing stove or reflector heater, radiation may account for a high proportion. In the condensing stove, an ordinary small open gas fire is set in a framework of iron columns, through which the products of combustion pass to a condensing chamber at the bottom of the stove. The reflector heater consists of an incandescent mantle set in a concave frame of polished copper, which projects the radiation in a relatively narrow beam.

Column radiators can also be heated directly by gas flames. In one well-known design, the burners are arranged one beneath each unit of a series of cast-iron columns, up which the hot products of combustion pass. The " gas steam " radiator, on the other hand, has a water chamber above a row of bunsen burners in the base, the steam generated rising up the columns of a radiator similar in design to those used in central heating installations. Either of these types can, of course, be provided with a flue, but a loss in efficiency is involved thereby. On the other hand, there is some risk of flueless gas heaters vitiating the air of a room, especially if the ventilation should be restricted.[21-25] The complete combustion of coal gas produces only carbon dioxide and water vapour, which are harmless; but should the combustion become incomplete, e.g., through lack of sufficient air or through the chilling of a flame by contact with some cold body, small quantities of carbon monoxide and oxides of nitrogen, both extremely poisonous, are produced. Most flames, indeed, appear to emit minute quantities of these gases, and their formation is encouraged by faulty conditions of burning. One part by volume of either per 10,000 of air breathed, is generally considered to be harmful, 5 parts per 10,000 actually dangerous, to health.

Under proper conditions of usage such concentrations are not likely to be reached, especially since owing to the high thermal efficiency obtained from flueless stoves relatively low rates of gas consumption are required. On the other hand, should there be too close contact between the flames and relatively cold bodies, such for instance as might be found with the flames turned high in a gas steam radiator, or should a bunsen burner " light back," unburned products of combustion may be liberated in injurious quantities. Heaters with luminous flames are probably the safest, since carbon deposition makes it essential to keep the flames from impinging on their surroundings; but for domestic use, or for any rooms which are occupied continuously, flueless stoves are not to be recommended.[26]

Electric heaters.

Many forms of electric heaters are on the market. These, like flueless gas stoves, generate heat equivalent to practically 100 per cent. of the energy consumption. The proportion, intensity, and distribution of radiation depend upon the design of the heater. When the heating elements are run at a very high temperature and backed by a reflecting case, intense localised radiation, which may amount to 70 per cent. of the total heat production, is obtained.[27-31] The effect produced, except for its uniformity, resembles that of a coal fire; but, unless the heater is placed under a flue, convection currents accelerate the general heating of the room, and so reduce the intensity of radiation required for comfort. When the heating elements are run at comparatively low temperatures by embedding the wires in insulating material, a larger heating area must be provided. The resultant radiation is more evenly distributed, and is also reduced in amount, particularly if special provision is made for circulating air around the heater, or otherwise increasing convection; its intensity locally may thus be greatly diminished in heaters designed for air-warming purposes.

Electricity is capable of meeting a wider range of requirements than any other method of heating. Not only is it extremely adaptable, and able to produce warmth in the most convenient form wherever needed but it is controlled simply by touching a switch, and neither makes dirt nor involves work. Unfortunately, however, as will be shown later, it is relatively very expensive.

Central heating by hot-water radiators.

In large buildings it is often convenient to heat the rooms from a central plant. The most usual method in this country is to circulate hot water from a coke-fired boiler through column radiators or pipes, suitably distributed over the building. Water heating efficiencies of 45 or 55 per cent. or more can be

obtained from such boilers, and the heat emitted from the furnace casings, etc., also contributes to the warming of the building. Most of the heat in the water is available for heating the required rooms if the insulation of piping, etc., along the rest of the hot-water circuit is adequate. It appears mainly in convection currents, radiation amounting only to some 10 to 30 per cent. of the energy emission, according to the shape, size, and surface coating of the radiator. The shorter a radiator the greater is its effective radiating surface, which includes the ends, compared with the total surface, all of which is effective for air heating. Hence, for any given temperature, the heat emission per unit area increases as the length of a radiator decreases. Similarly, single-column radiators emit heat more rapidly per unit area than double-column radiators, double-column more than three-column, and so on. The usual aim, however, is to pack as large a heating surface as possible into a small overall area, and to rely for comfort upon air heating. The custom of using metallic paints for hot-water radiators, although it reduces the radiation considerably, only affects the aggregate heat emission to the extent of a few per cent.[32-36]

Owing to the large quantities of water which must be heated, low-pressure hot-water systems are not suitable for intermittent heating, and are usually run continuously. High pressure and high temperature systems, in which pipes and heating coils of relatively small size form a closed circuit through the building, are more flexible, and the installation costs are lower; but an unpleasant smell is caused by the charring of dust on hot surfaces. Further the low-pressure apparatus is more durable, safer, and more easily manipulated than the high. It is used almost exclusively in this country.

Central heating by extended surfaces.

With a view to rendering lower air temperatures comfortable by increasing the proportion of radiation emitted, while maintaining fairly uniform conditions in a room, hot-water circulation has recently been utilised to warm relatively large, freely-exposed surfaces. In the system known as panel heating the hot-water pipes are buried beneath the plaster of walls or ceiling. Radiators consisting of painted metal plates on which pipes carrying hot water are mounted, have also been introduced. These are insulated on the back, and are designed to be fitted against walls or ceilings, to replace the usual sectional radiators.[37]

The rate of heat emission from such surfaces, which will have nearly black body emissivity for radiation unless they are coated with a metallic paint, can be deduced for the vertical position from the table given on page 468. About 50-55 per cent. of the emission will be as non-visible radiation, the remainder being spent in air warming. When the heated area is on the ceiling, however, the emission is more difficult to estimate, since the extent to which convection is checked will vary with the conditions. For still air and a non-porous ceiling it might be expected to be negligible; but in practice there is a limited amount of convection due to non-uniformity of heating, draughts across the ceiling, porosity, etc.

It is sometimes claimed that the air of a room is not warmed by ceiling heating. This, of course, is a fallacy, even should direct convection be entirely inoperative; since the non-visible thermal radiation, although it does not heat the air directly, is absorbed by the contents of the room, which then warm the air. The real problem in ceiling or wall heating is to compute correctly the area and temperature of heating surface required to give sufficient radiation to impart a sensation of comfortable warmth at the resultant temperature of air and other surroundings. Since, however, direct advantage is taken by the occupants of the low-intensity radiation, a somewhat reduced total energy emission suffices to make a room comfortable. This method of heating should thus involve a correspondingly reduced fuel consumption.

In general, the smaller the area of the heated patch, the less uniform will be the heating effect in a room. Economic considerations forbid the warming of very large patches, but the distribution from a limited area can be improved by using several separate panels suitably spaced, or by running a strip of heating around a room. Alternatively, the heating effect may be deliberately concentrated on the window side of a room to counterbalance the effects of cold down draughts from, and radiation to, the glass.

Panel heating by embedded pipes cannot be regulated quickly, owing to the large mass of heated material, and there are considerable practical difficulties in its application. Such drawbacks are not associated with radiators of extended surface, but their interference with schemes of decoration sometimes precludes

their use. Generally speaking this type of heating is preferable to column radiators from the point of view both of comfort and appearance. It should also allow of appreciable fuel economy.

Central heating by warm air.

Workshops and factories of extensive area are often heated by forcing large volumes of warmed air into the rooms through ducts and gratings. This may be removed either through artificial outlets or by open windows. The chief aim is to distribute inlets and outlets in such a manner as to secure uniform conditions, avoid unpleasant draughts, and provide ample fresh air at breathing level.

It is now generally agreed that an upward system of ventilation with exits near the ceiling, since it acts in conjunction with the warm currents rising from the occupants of a room, is the best. Again, natural ventilation by the escape of warm used air through windows, shafts, louvres, etc., and its replacement by cool air drawn from suitable sources, is considered preferable to artificial systems, provided it is able always to produce the necessary air change. It is usually desirable, however, that artificial means of increasing ventilation should be available, and exhaust ventilation is often employed, by the provision of fans, or by heating the air, in extraction shafts.

Warm air circulation is a relatively common method of heating dwelling-houses in America, and attempts are being made to popularise it in this country. Very simple systems may be installed, in which air warmed by circulation around the inner casing of a furnace, generally in the basement, either obtains access through a grating to the hall or some other suitable spot, and subsequently rises through the building or is led through pipes to several gratings, suitably located. Even in relatively small installations 50 or 60 per cent. of the heat of the coke or anthracite burned in the furnace can be obtained in the outpouring air. The heat from the furnace casings is also effective in the building. A recent investigation in the U.S.A. showed an overall efficiency of 89 per cent. from such a system, the chimney losses in sensible heat and unburned products amounting only to 11 per cent. Anthracite was the fuel used.[39] The capital cost of such equipment is low, but warm air heating is not in favour with modern physiologists, and there is a tendency for the rising streams of hot air to carry dust.

Heating from central stations.

Groups of houses can be warmed and supplied with hot water from large central stations, which can be run more efficiently than individual installations. Alternatively, the waste heat from electricity-generating stations may be used to heat buildings in their vicinity. Many schemes of this kind have been adopted in America, where the winter climate makes some form of central heating indispensable. Either steam or hot water may be used as the heating medium. Such systems cannot be expected to meet with much success in this country except for blocks of flats and the like, or in cases where the conditions are particularly favourable.[40, 41]

Cooking and hot water supply.

The multiple capacity of the kitchen range makes it almost impossible to assign to it with any real meaning an aggregate efficiency figure. The fire may be supplying still more heat to an already overheated kitchen, and yet be kept going for the production of hot water or to carry out cooking operations. On the other hand, in winter a large fire may be necessary for warming the kitchen, although the incidental water and oven heating are of no use. Under the best conditions, solid fuel ranges with back boilers, whether of old-fashioned or modern design, may give water-heating efficiencies of 15 to 20 per cent. The open fire gives 5 or 10 per cent. of radiation, and there is in addition diffuse non-visible radiation from the heated surface of hot-plate, oven, etc. Barker found that the heat absorbed by the ovens of ordinary kitcheners varied from about 3 to 6 per cent., but the heat actually communicated to the food was at most 2 or 3 per cent. even for full loading.[43]

The efficiency of small modern coal-fired kitchen ranges as measured in the laboratory is little better than that of old-fashioned types; but in ordinary use they are far less clumsy and more convenient, and since they are more easily controlled may actually perform the necessary services on a reduced fuel consumption. Some of these are built more or less directly upon the lines of former types. They have an oven

at the side and a back boiler, but the fire, which is open, is usually set low and resembles a modern sitting-room grate. Certain other individual features, varying from grate to grate, may also be introduced. Other recent ranges are of the "convertible" type, closed when the oven is in use, but very similar in appearance to a sitting-room grate when the hot-plates are raised, the oven door being made to resemble a canopy.

In many ranges coke, especially if of an easily combustible variety, can be substituted with advantage for coal; but it usually fails to heat top-heated ovens satisfactorily.

Independent boilers, where the fire is more or less completely surrounded by the boiler surfaces, give water-heating efficiencies of about 40 to 50 per cent. from moderately dry coke, or 30 to 45 per cent. from coal, calculated as delivered at the taps so soon as temperatures suitable for household use have been reached.[42] Modifications of such boilers, which may include an oven and one or two hot-water radiators, and which can be used with an open fire when desired, have been introduced as an alternative to the ordinary kitchen range. Many of these can be run on a low fuel consumption, and their appearance allows of their introduction into the kitchen or living room. For all-round efficiency, no other ranges on the market are to be compared with them.

Gas or electric cookers are far more efficient than coal ranges. Tests made by Barker showed that the calorific value of the gas used to prepare a three-course meal for seven people was only one-fifth of that which would have been needed for the same purpose in a coal range.[43] Experiments made on similar lines in America gave results varying from one-fourth to one-thirteenth for different meals. The energy used in an electric cooker was found to be less still, representing from one-fourteenth to one-fortieth of the requirements of a coal range.[44]

For boiling purposes, thermal efficiencies from 40 to 55 per cent. can be obtained from properly constructed commercial gas rings.

The efficiency generally increases as the distance between the burner and the cooking utensil is reduced; but if this becomes too small, carbon monoxide may be produced in objectionable quantities. Hence careful adjustment is necessary if the products of combustion are allowed to mix with the room air.[45-48]

The thermal efficiency with which boiling operations can be carried out on electrically-heated hot-plates is very variable, but is generally between 30 and 60 per cent. Self-contained vessels give much higher values, there being practically no heat losses other than those from exterior surfaces.

For water heating on the large scale, efficiencies as high as 80 per cent. can be obtained from either gas circulators or geysers, while electric immersion heaters give nearly 100 per cent. efficiency in well-lagged boilers.[49-52]

Which fuel, or which installation, will prove the most economical, whether for heating, cooking or hot-water supply, depends upon a variety of factors, to be considered in the next chapter.

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Chapter 3.

COSTS OF HEATING.

By Margaret Fishenden, D.Sc., F.Inst.P

Gas has for some years been increasing rapidly in popularity for household purposes, particularly in certain districts. In London, for instance, the number of gas cookers and gas fires in use has quadrupled since the beginning of the century. Electric heaters and cookers are also gaining ground.[1] By far the greater proportion of the domestic heat requirements of the country as a whole, however, are still met by raw coal, of which 40 million tons a year are consumed for non-industrial purposes. This is greatly in excess of the coal dealt with by gasworks and electricity generating stations together, for the production of gas and electricity for all purposes, both industrial and domestic.[2]

That such a state of affairs should continue is undoubtedly due largely to the fact that solid fuel is relatively so cheap on a thermal basis, that, notwithstanding its poor efficiency in use, nothing can compete with it in low cost for all-round family needs.

Cost of potential heat in different fuels.

In recent years, the prices of fuels have been subject to wide fluctuations, and it is somewhat difficult to decide which averages should be taken as applicable to normal conditions. Table I. gives the cost of quantities of coal of calorific value 14,000 B.Th.U.'s per lb. at 40/- to 60/- per ton ; coke of calorific value 12,500 B.Th.U.'s per lb. at 30/- to 50/- per ton; anthracite of calorific value 15,000 B.Th.U.'s per lb. at 80/- to 100/- per ton; gas at 6d. to 1/6 per therm; and electricity at 1d. to 3d. per B.O.T. unit; sufficient in each case to produce one therm (100,000 B.Th.U.'s) of heat, assuming maximum theoretical efficiency. For the purposes of the comparisons made in this chapter, the following prices have been adopted:—Coal, 50/- a ton; coke, 45/- a ton; gas, 10d. a therm; electricity, 1d. a B.O.T. unit (i.e., one kilowatt-hour).

Table I.

Coal of Calorific Value 14,000 B.Th.U.'s per lb.:— Ton.	Cost per 100,000 B.Th.U.'s of Potential Heat. Pence.	Anthracite of Calorific Value 15,000 B.Th.U.'s per lb.:— Ton.	Cost per 100,000 B.Th.U.'s of Potential Heat. Pence.
At 60/-	2.3	At 100/-	3.6
At 50/-	1.9	At 90/-	3.2
At 40/-	1.5	At 80/-	2.9
Coke of Calorific Value 12,500 B.Th.U.'s per lb. :—		**Gas of any Calorific value :—**	
Ton.	Pence.	Therm.	Pence.
At 50/-	2.1	At 1/6	18
At 40/-	1.7	At 1/-	12
At 30/-	1.3	At 6d.	6
		Electricity :— Unit.	Pence.
		At 3d.	88
		At 2d.	58
		At 1d.	29

Cost of equivalent heat production by different fuels.

Under ordinary conditions, the combustion of solid fuels is so far from complete that the heat generated falls considerably short of their calorific value, while the heat which can be usefully employed

1. "Atmospheric Pollution and Fog Prevention." Extract from Minutes of L.C.C., July 3rd, 1923.
2. See Annual Reports of Secretary for Mines.

is less still. On the other hand, gas, in properly designed appliances, produces heat more nearly commensurate with its theoretical value, although again it is not possible to utilise the whole of this except in flueless heaters. Thus, as we have seen, the room-heating efficiency of the best open fires is only about 25 per cent. of the calorific value of the coal burned, 30 per cent. for dry coke or anthracite, and 55 per cent. for gas. Closed stoves emit into a room 45 to 55 per cent of the energy of the coke burned, or more if they are centrally situated, or if the draught is properly controlled. Flueless gas heaters, or electric heaters of any kind, give practically 100 per cent. efficiency. Central heating, whether by hot-water radiators or by the introduction of hot air allows of 50 per cent. of the heat of the fuel being utilised for room heating, even in small installations; while in large plant 65 to 70 per cent. efficiency should be reached.

From these figures, the approximate costs of producing equal quantities of heat in a room by different methods can be calculated and are shown in Table II. The proportions of radiation and convection contributing vary widely.

TABLE II.

Coal of Calorific Value 14,000 B.Th.U.'s per lb.:—	Ton.	Cost of producing 100,000 B.Th.U.'s in a room. Pence.
In open grate.	60/-	9.2
	50/-	7.6
	40/-	6.0
Coke of Calorific Value 12,500 B.Th.U.'s per lb.:—		
	Ton.	Pence.
In open grate.	50/-	7.0
	40/-	5.7
	30/-	4.3
In closed stove, or central installation.	50/-	4.2
	40/-	3.4
	30/-	2.6
Anthracite of Calorific Value 15,000 B.Th.U.'s per lb.:—		
	Ton.	Pence.
In open fire.	100/-	12.0
	90/-	10.7
	80/-	9.7
Anthracite of Calorific Value 15,000 B.Th.U.'s per lb. :—		Cost of producing 100,000 B.Th.U.'s in a room.
In closed stove, or central installation.	100/-	7.2
	90/-	6.4
	80/-	5.8
Gas of any Calorific Value :—		
	Therm.	Pence.
In open fire under flue.	1/6	32.7
	1/-	21.8
	6d.	10.9
In flueless heater.	1/6	18
	1/-	12
	6d.	6
Electricity :—		
	Unit.	Pence.
In any heater.	3d.	88
	2d.	59
	1d.	29

The above figures show that coke is the cheapest available fuel for maintaining a continuous supply of heat to a room, especially if used in central heating installations or closed stoves. When burned in an open grate its cost is much the same as that of anthracite either in individual stoves or in a centralised system, but is appreciably less than that of open fires of anthracite, and slightly less than that of open fires of coal. Next in order of cheapness comes the flueless gas heater, followed by open gas fires, and, most expensive of all, electricity.

Such a comparison, however, which takes account neither of the superior flexibility of gas and electric heaters, which can be turned on or off at will, and sometimes also are portable, nor of the saving in labour effected by their use in place of solid fuel, is not a true indication of the position, although it serves as a working basis for more reliable computations.

Further, since the object of artificial heating is rather to keep warm the occupants of a room than the room itself, the radiant energy requisite for comfort is not necessarily the thermal equivalent of the air heating demanded for equal comfort. In a large room, the localised radiant energy which would keep a single occupant warm would be altogether inadequate to bring the whole of the room to a comfortable temperature. Since the occupants themselves generate heat, and therefore contribute to the general warming of a room, an increase in their number reduces the amount of artificial heat necessary to keep the room at a given temperature. On the other hand, when an open fire is relied upon for comfort, more intense radiation is needed as the number of people to be kept warm increases. The reason for this is that the heat which they produce is less evident, on account of the high rate of ventilation associated with open fires; while, owing to the extra seating space required, positions further away from the fire must be occupied. Thus, which installation will be the most economical depends, among other things, upon the size of a room and the number of people using it. It is also associated with the nature of the construction. Further, since some methods of heating respond to control far more readily than others, appliances which are cheap for continuous use do not necessarily remain so when required only intermittently.[3-4]

Cost of continuous heating by different methods.

Estimates of the running cost of heating by different methods rooms of ordinary construction and various sizes, containing different numbers of people, still show that for continuous use, say over a 16-hour day, some form of solid fuel installation is always the cheapest. Closed stoves or central systems are usually the lowest of all in running cost, even when kept alight night and day, although they are probably not so healthy as radiation heating. Where only a few people are to be provided for, open coal or coke fires may become the cheapest, especially in large rooms, but they are as a rule too troublesome for buildings of many rooms. Their effect, moreover, may be so one-sided as not to produce a high degree of comfort in very cold weather; but this disadvantage can be avoided by the use of screens, which are a simple and efficacious aid to fuel economy and might well be employed more extensively.

As may be seen from Table II., gas at 10d. a therm costs more than twice as much as solid fuel at 45-50 shillings a ton, whether in flueless stoves as compared with closed coke stoves or central heating installations, or in open fires as compared with open coal or coke fires. But since the thermal efficiency with which gas is utilised is in either case about double that for solid fuel, while, if allowance is made for the coke produced, the thermal efficiency of its production from coal is about 50 per cent., the return from a given quantity of coal is little affected by first converting it into gas, although its cost to the consumer is increased thereby.

Electricity does not compare well with solid fuels for continuous heating. At 1d. per B.O.T. unit, the cost is about eight times as much as solid fuel at 45/- to 50/- a ton in closed stoves or central installations; for the production of high temperature radiation the cost is about five times as much. The coal consumed in the generation of electricity would be twice as effective if burned directly in solid fuel appliances.

Discontinuous heating by different methods.

For intermittent heating, a very different state of affairs obtains. Provided that gas fires or electric heaters are turned off immediately a room is vacated, their cost will be proportional to the aggregate time the room is used, if the fact that it becomes warm less rapidly with discontinuous heating than with continuous heating is neglected. Central heating or closed stoves still remain the cheapest and most suitable method if a large proportion of the floor space is required. For a few people only, especially in a large room, open fires have the advantage. But for radiation heating, gas, apart from being far cleaner and more convenient, costs no more than coal or coke, and actually entails a reduced initial coal consumption; while the cost of electricity has been reduced to about twice that of solid fuels, and may in practice be cut

3. Barker "Fuel Economy in Private Households." *The Builder*, September 27th, 1918, to February 7th, 1919.
   Also "Experiments on Fuel Economy in Working Class Tenements." *The Builder*, April 23rd to May 14th, 1926.
4. Fishenden and Willgress. "The Heating of Rooms." Fuel Research Board Technical Paper No. 12.

down still further owing to the portability of electric appliances. For when a heater can be moved into the most advantageous position, a minimum output suffices for comfort. The intermittent use of electricity in these circumstances, therefore, would not be wasteful of our coal supplies.

Hot water production by different methods.

Hot water requirements on the large scale are easily and cheaply met either by an independent boiler or indirectly from a central heating plant. Coke at 45/- a ton in such appliances costs about one-third as much as gas in circulators or geysers, or about one-third as much as electricity at 1d. a unit, for equal hot water production. Even the ordinary back boiler heats water slightly more cheaply than gas, or at about one-third the cost of electricity. There are, however, many instances where, all things considered, gas for water heating, particularly with an intermittent demand, may prove more economical than solid fuel, since not only can storage losses be minimised but attendance avoided. Hence gas is suitable for supplying the taps in cloakrooms, etc., or as a substitute for back boilers in summer. Electricity at 1d. a unit is far too dear for water heating except in special cases, but at less than ½d. a unit it becomes a serious competitor with gas at 10d. a therm.

Cooking by different methods.

It is not easy to estimate with any accuracy the relative costs of cooking by alternative methods, even if the water heating and room warming capacity of the solid fuel range is left out of the question, for the comparison depends upon the nature of the meal to be prepared. Generally speaking, however, gas at 10d. a therm compares well with coal at 50/- a ton. So also probably do the best electric cookers, provided the oven is in use; but for hot-plate work alone gas would be considerably cheaper than electricity, unless self-contained vessels were used exclusively. Cooking in hotels, restaurants, and similar establishments, is still carried out largely by solid fuels, but there is a growing tendency for the substitution of gas or electric ranges, even when entailing increased running costs. The saving effected in such cases by avoiding handling coal and lighting and attending to fires is often of more importance than the consideration of fuel costs. Further, uncertainties as to the cooking results are greatly diminished by the use of appliances which can be controlled with accuracy.

Heating arrangements for large buildings.

The fuel problem of large buildings, whether business premises such as offices and shops, or residential premises such as hotels and blocks of flats, is relatively simple, since a heavy load must be met throughout the day. Similarly, the well-to-do classes, occupying large houses and demanding a high standard of comfort, have heat requirements on a comparatively large scale.

In such cases central heating of some kind is almost essential. Both heating and hot water production can be carried out most cheaply from coke boilers, although special circumstances may sometimes lead to the adoption of oil or gas firing. It is desirable from considerations of comfort and health either to use extended heating surfaces or, alternatively, if employing column radiators or warm air circulation, to run the heating on a somewhat reduced scale and supplement it by small open fires, using solid fuel in continuously occupied rooms and gas or electricity in rooms needed only for short periods. This, of course, entails increased installation costs, and involves extra work which in many cases would make its adoption practically impossible. On the other hand, chimney flues have considerable value as ventilators.

For small buildings.

Large houses are in the minority, and the real difficulty in ensuring economical fuel consumption by efficient, up-to-date methods is found in small houses. In the domestic field nearly ten million families, consisting on the average of less than five members, form ten million separate units, each with its individual arrangements and individual requirements for heat supply.

Again, the financial resources of different classes vary greatly, making sometimes comfort, sometimes economy, the primary consideration; in many cases time may be more valuable than fuel, or coal may be out of the question on account of the dirt it produces. Even in the same grade of society, some families are accustomed to use far more hot water per head than others; some have relatively heavy cooking requirements, while others prefer to keep their houses very warm. Hence it is impracticable to lay down specific rules as to the most economical installations. Only broad general recommendations can be made.

For warming purposes, central installations have been shown to be the cheapest in relation to the effect produced; but they do not allow of warming a house throughout on so low a fuel consumption as may suffice, even in intrinsically extravagant appliances, for the individual warming of one or two rooms only. Again, there is a minimum rate at which independent coke-fired boilers can be run satisfactorily, and this may produce hot water in excess of the requirements. As the means of a household become more straitened, therefore, the heating problem gradually changes from that of selecting the most suitable apparatus to perform services regarded as indispensable, to that of expending to the best advantage a limited sum.

Whenever the demand for hot water is heavy, it will pay to run a coke-fired boiler. If the conditions of living are such that rooms other than the kitchen are in general use, this should be large enough to be capable of maintaining a limited number of hot water radiators; auxiliary heating being carried out by open fires of solid fuel, gas, or electricity, according to the circumstances; cooking by gas or electricity. If radiators are dispensed with the boiler may be of the open fire type, serving to warm the kitchen in cold weather, yet allowing it to be kept cool in the summer. Ranges based on independent boiler design, and including an oven, can be obtained, and give a very high over-all efficiency where both cooking and hot water requirements are heavy, but they tend to overheat the kitchen in warm weather.

In households where only a moderate amount of hot water is needed, coke-fired boilers of any type may be extravagant, notwithstanding their high thermal efficiency. For although the coal-fired kitchener with back boiler is dirty and troublesome, and judged on hot water production or cooking separately gives a poor return for the fuel expended, it provides from a single fire, oven, hot-plate, bright radiating surface and hot water, all of which may suffice for requirements. In such cases it is likely to cost less for fuel than any other installation, especially if of some good, modern design. Alternatively, especially if the kitchen is used as a living room, an open sitting-room grate with back boiler, and a gas cooker, may be used. In winter the former arrangement would probably be the cheaper, since the kitchen fire would have to be kept going for warming purposes, and a considerable additional consumption might be involved if cooking were carried out by gas. But in summer the latter arrangement would allow of occasionally dispensing altogether with a kitchen fire.

Coke should whenever possible be used even in kitcheners and open grates, for if of good quality it is frequently more efficient and cheaper than coal. By such means, and by choosing carefully equipment appropriate to the requirements, not only can fuel economy and comfort be achieved, but progress made towards the abolition of smoke.

PART VIII.—THE COMPLETE UTILISATION OF FUEL ENERGY.

Chapter 1.

PRINCIPLES OF HEAT TRANSMISSION.

By J. W. Hinchley, Wh.Sc., A.R.S.M., M.I.Chem.E., F.I.C.

Little progress can be made in the efficient utilisation of heat energy without some knowledge of heat transmission, and to obtain the most efficient solution of a practical problem, a very thorough knowledge is generally necessary.[1]

There are three distinct ways in which heat may be transferred :—

(*a*) By wave motion through the ether; radiation.

(*b*) By direct molecular motion transfer; conduction.

(*c*) By molar transfer; convection.

Modern heat theories suggest that the molecules of all bodies are in a state of vibration, and that the average period of vibration is a measure of the temperature. At the boundary of a solid or liquid body, this molecular motion appears to give rise to etheric waves corresponding in average frequency with the molecular vibrations, *i.e.*, with the temperature. An examination, therefore, of the wave lengths of the radiation from an object will give a determination of the temperature of the radiation emitting surface.

In the case of gases, the molecular vibration gives rise to etheric waves also, but while in solids the etheric and molecular vibrations are in tune, in gases, the etheric vibrations passing through them may affect the molecular agitation but slightly. Tyndall, in 1859, found that while air, oxygen, hydrogen and nitrogen had little effect, carbon dioxide, water vapour and the vapours of organic compounds had a very marked absorption effect on radiant heat.

Prevost's Theory of Exchanges. At the absolute zero of temperature—273° C., the molecules of all substances are at rest; at all temperatures above that, molecular vibrations exist, which set up etheric waves to an extent determined by the temperature and the nature of the molecules. This was the idea of Prevost in 1792; "a body emits an amount of radiant energy that depends only on its own temperature and not on that of its surroundings." It also absorbs radiations to which it is its nature to respond. Therefore, when a body in an enclosure is at constant temperature, the energy radiated by it is equal to that absorbed; this is Prevost's law of exchanges. A body can never get hotter by radiant energy than the body which gave rise to the radiation. There is a certain ratio between the emission and absorption behaviour of every kind of matter.

Kirchoff's Law. Kirchoff's law states that the ratio of the coefficient of emission to the coefficient of absorption is the same for all substances whatever and depends only on the temperature or frequency of the radiation in question. A body which completely absorbs all radiations falling on its surface is defined as a "black body"; such a surface has the property of emitting the complete radiation. No substance has been found which fulfils perfectly the conditions of a "black body," but the radiation from a uniformly heated cavity fulfils "black body" conditions, is independent of the material forming its walls and is a function only of its temperature.

Unfortunately, practically all materials are selective in their emitting and absorption powers, that is, the coefficient depends on the wave length of the radiation.

Stephan's Law. The law relating to the distribution of radiant intensities in the spectrum of the radiation from a "black body," although well established, will not help us at present in our practical problems, but a law of total radiation, suggested by Stephan in 1879, from a consideration of Tyndall's experimental data, is a great service to the chemical engineer and has been verified by direct experiment by several physicists. This law states that the total emission of thermal radiation of all wave lengths, passing from a "black body" at one temperature to another at another temperature, is proportional to the difference of the fourth powers of the absolute temperatures of the two bodies. Quantitatively, if T_1 and T_0 are the absolute temperatures of the bodies in question in degrees Cent., then :—[2]Radiation in ergs per sq. cm., per sec.$=5.72 \times 10^{-5}$ $(T_1^4 - T_0^4)$.

It will be realised, therefore, that the estimation of thermal changes through radiation is an extremely difficult matter, for simple conditions for the application of the laws relating to radiation are never realised in industrial plant. Since, however, an error of 10 per cent., or even more, in such an estimate is usually of little importance, compared with a "rule of thumb" guess, the chemical engineer makes useful quantitative generalisations of practical utility, always bearing in mind the possible errors.

In a practical problem, neither emitting nor receiving bodies are "black," nor are they grey; the receiving body may not fill the angle of vision of the hot body; the surfaces of neither are smooth nor regular and usually have irregular cavities. All these data must be estimated as nearly as can be done, but for the purpose of design the estimated air temperature of the factory may be taken as that of the cool surroundings. A useful estimate of the loss of heat from a surface is then made by the following formula :—

$$L_r = a \left\{ \left(\frac{T_p}{100}\right)^4 - \left(\frac{T_a}{100}\right)^4 \right\}$$

Where : L_r = Loss of heat in calories (large) per sq. metre per hour; T_p = Absolute temperature of the plant surface in degrees Cent. ; T_a = Absolute temperature of the air of the factory ; a = Coefficient of emission of radiation. Most of the coefficients of emission determined by Peclet in the middle of the last century may be used in this formula without serious error, although his constants were used in a different formula which suggests that they are nearly 2 per cent. low. In recent years, however, more accurate determinations have been made.

The following table is useful for estimating purposes :—

Values of *a* (calories per sq. m. per hour).
(Black body=4.57).

Material.	Peclet.	Recent. 4.6.7.		Material.	Peclet.	Recent. 4.6.7.	
Copper, bright	.16	.46		Gold	—	.24	
dull	—	1.19	.79	Zinc, bright	.24	.46	
highly oxidised ...	—	3.29		dull	—	1.00	
Cast iron, bright	—	1.00		Tin	.21	.46	
new	3.17			Nickel	—	1.06	
oxidised	3.36	2.83	4.46	Mercury	—	1.05	
Wrought iron, polished ...	.45	.93	1.22	Platinum	—	1.10	
ordinary ...	2.77			Glass	2.91		
oxidised ...	3.36	4.1	4.38	Stoneware	—	3.79	
black-leaded	.63			Brick	3.60		
Brass, bright	.26			Sand	3.63		
mott.	—	1.06		Lampblack	4.01		4.42
Monel metal	—	.43		Aluminium Paint	—		2.28
Silver	.13	.14		Lime Mortar	—		4.27

It will be seen that extremely high rates of heat transmission may be obtained by radiation methods, and since the rate increases as the fourth power of the absolute temperature, for the highest efficiency in heat transmission, the radiating surface should be maintained at as high a temperature as possible.

The provision of ribs, cavities or corrugations on the hot or cold bodies will not much affect the transmission of heat by radiation, excepting so far as it may tend to "black body" conditions on the cavity portions of the areas.

The loss of heat from surfaces may be diminished considerably by polishing the surfaces, by galvanizing painting, etc.

The provision of a shield or screen round a plant will diminish loss by radiation by increasing the temperature of the cold body; in this case, the surface of the plant will increase in temperature, but on account of the law of exchanges, the total loss of heat by radiation will be reduced.

It is interesting to determine the fuel losses due to the exposure of furnace and other plant in the open air, and to examine the economic aspect of its adequate protection. An iron cased plant with a skin temperature of 85° C. will lose (on a still summer night) about 1,200 calories per square metre per hour, of which about one-half will be due to direct radiation, of which, again, about one-half could be saved by the flimsiest protection.

The effects of radiation on the accuracy of the determination of the temperature of a gas in a furnace or flue by means of any thermometric device should not be overlooked. The readings of such instruments will be affected by the radiation from the walls and any differences between the temperature of the gas and its surroundings will mean errors. A single or double shield of silver foil round the bulb of any thermometric device usually reduces this error to small dimensions.

Conduction.

The transmission of heat by conduction is a comparatively simple matter, provided that the materials are uniform.

In any material, heat flows from places of high temperature to places where the temperature is lower, until equilibrium is established. The rate of flow is proportional to a constant for each particular substance, called the coefficient of heat conductivity, to the difference of temperature, and inversely proportional to the distance between the places in question.

Coefficient of Thermal Conductivity. If two opposite faces of a metre cube of material be maintained at a difference of temperature of 1° C., then the number of calories propagated through the material per hour is the chemical engineer's coefficient of thermal conductivity. It is usually more convenient, for chemical engineering calculations, to use the reciprocal of this coefficient, viz., the coefficient of resistivity.

The transmission of heat through a simple wall whose area is a and whose thickness is t, when the temperature difference between its faces is θ degree Cent., is given by the equation: $Q = \frac{a\,\theta}{r\,t}$

Where Q is "the quantity of heat passing" through the wall in calories per hour, and r is resistivity of the material of the wall.

If there are several layers of material between the surfaces of high and low temperature of resistivities of r_1, r_2, r_3, etc., and thicknesses of t_1, t_2, t_3, etc., then $Q = \frac{a\,\theta}{r_1\,t_1 + r_2\,t_2 + r_3\,t_3 + \text{etc.}}$

It should be noted, however, that these heat coefficients are not, strictly speaking, constants, but vary somewhat with the composition of the material and the temperature. The coefficients of resistivity for brickwork, sand, asbestos and similar materials, vary considerably with the size of the constituent particles and the compactness of the mass, so that all such coefficients must be considered "utility" constants. One must be prepared, therefore, for differences, but not such as will vitiate a practical conclusion.

Where the surfaces of different materials come into contact, it is obvious that the heat transmission across the boundary must depend on the character of that contact. At places other than the real point of contact radiation must take place and the nature of these surfaces will play a considerable part in determining the amount of that radiation. In fact, the efficiency of most heat insulators lies in their porosity, by which real thermal conduction through the solid material is reduced to a minimum.

The effect of this lack of contact between different materials is often estimated as surface resistance. Where metallic substances are in contact, these surface resistances become of great importance, while in the case of bad conductors, the surface resistance usually may be neglected. If surface resistance be taken into account, the formula mentioned above becomes, in the case of a composite wall with surface resistances of s_1, s_2, etc., $Q = \frac{a\,\theta}{r_1\,t_1 + s_1 + r_2\,t_2 + s_2 + r_3\,t_3 + \text{etc.}}$

Unfortunately, as already stated, the thermal resistivity of a material varies with composition and temperature. In the case of ordinary materials, variation of composition may affect the value of this coefficient by as much as, or even more than, 25 per cent. and, in addition, temperature changes also occur.

For nearly all chemical engineering conclusions the thermal resistivity of all metals may be assumed to be constant, and since in ordinary cases of heat transmission between fluids conduction plays a very small part, no practical error on that account will be made.

The thermal conductivities of liquids are very low and are comparable with those of the worst conductors, e.g., brickwork usually has a conductivity about three times that of water or salt solutions and about nine times that of most organic liquids. In the case of gases, the coefficient is still lower and is about one hundredth that of brickwork, except in the case of hydrogen, which is about seven times that of air and about one-tenth that of brickwork. In the case of a simple wall with parallel faces kept at uniform temperatures, the surfaces of equal temperature, the isothermal surfaces will be parallel to the faces of the wall and the heat flow will be in straight lines at right angles to these faces. If, as is usually the case, the material is not in the form of a flat wall, or the conditions of heating are not uniform, the isothermal surfaces will be curved and it will be necessary to introduce a " shape factor " in our calculations. The shape factor of a sphere and of a cylinder are easily calculated and a satisfactory geometric estimate for other forms is not impossible in practical estimating work.

A careful examination of the following table will give an illuminating view of the thermal behaviour of common substances and materials of construction. The conductivities and resistivities are given in chemical engineering units (calories per square metre per metre per hour) the diffusivities[8] are given in C.G.S. units. The temperatures of the materials are the useful average in each case.

Material.	Conductivity.	Resistivity.	Diffusivity. $h^2 = \frac{k}{cp}$
Aluminium	177	.00578	.826
Copper	327	.00306	1.133
Wrought iron	51.5	.0194	.173
Cast iron	40	.025	.121
Steel	38.5	.026	.130
Lead	29.5	.0339	.237
Mercury	7.24	.138	.0327
Nickel	49.7	.0201	.152
Silver	357	.0028	1.737
Tin	52.2	.0192	.407
Zinc	94.3	.0106	.402
Brass	93.6	.0107	.339
Firebrick	1.44	.694	.0074
Building brick	.72	1.39	.0050
Wood (pine). Across grain	.108	9.26	.0023
With grain	.324	3.09	.00068
Asbestos	.166	6.04	.0035
Wood charcoal	.0612	16.3	—
Concrete	.792	1.26	.0056
Wool	.0504	19.8	—
Magnesium carbonate steam pipe covering	.0612	16.3	—
Water	.515	1.94	.00143
Alcohol (and many organic liquids)	.0968	10.3	.00072
Hydrogen gas	.1307	7.65	.104
Carbon dioxide gas	.0117	85.5	.082
Air	.0198	50.5	.179

This discussion relates only to heat flow when a steady state of temperature has been established, a condition common in chemical engineering work. When, however, the temperature is a varying one, the heat flow will depend on the thermal capacity of the material as well. In fact, the heat diffusivity, i.e., the thermal conductivity divided by the heat capacity per unit volume determines the rapidity with which the temperature changes take place. A consideration of this fact often places materials for varying thermal conditions in a different order of usefulness.

The thermal conductivity of gases is a very important factor to the chemical engineer, but is complicated by radiation and convection. Generally, the transfer of heat to and from a gas, from and to solids is an extremely complicated problem in which all three methods of heat transfer enter in important amounts. Assuming that the molecules of the gas are force centres repelling each other according to the fifth power of the distance between them, Maxwell showed that the thermal conductivity will be given by the equation[2]: $K=fC_v\eta$; where C_v is the specific heat at constant volume, η the viscosity and f a factor of 2.5. Experimental data suggest that for monatomic gases this value is correct, but in the case of diatomic gases the value appears to be 1.75. It may be remarked that the thermal conductivity of a gas, in the light of the kinetic theory, should vary as the square root of the absolute temperature.

Convection.

The transmission of heat by the movement of the material itself, or convection, is limited to liquids and gases, and occurs so readily that it is never really absent in any practical case. On the other hand, the efficiency of heat transmission, where fluids are concerned, is generally dependent upon convection being stimulated or forced.

It is well to distinguish between natural convection and forced convection. In the former case, density differences which occur, due to temperature differences, give rise to gravity currents, which tend to increase the thermal changes. In the latter, the movement of the fluid is determined mechanically and the heat flow from the solid to the fluid or from the fluid to the solid is proportional to the temperature difference. The experimental evidence shows that the rate of heat flow may be assumed to be proportional to the temperature difference and the velocity of the fluid.

In the case of natural convection, the rate of heat flow is proportional to the temperature difference raised to the power of 1.2 approximately. The latest investigations give the power as $\frac{5}{4}$.

A convenient formula for the determination of the loss of heat from surfaces exposed to the air by convection is: $L_a = \delta\ (T_p - T_a)^{\frac{5}{4}}$. Where L_a is the loss in calories per sq. metre per hour, T_p is the temperature of the surfaces, and T_a the temperature of the air. δ is a factor involving the shape and position of the surface.

The factor δ may vary from about 2.2 to 3.3, but for most factory plant a value of 2.9 is reasonably accurate. For purposes of design, a factor of 3 is often adopted by chemical engineers. Recent experimental work shows that vertical and horizontal surfaces facing upwards appear to give the same air contact or natural convection loss, while horizontal surfaces facing downwards give about half this loss.

The total loss of heat therefore from hot surfaces by radiation and air contact or by convection in still air may be estimated for the purpose of design with sufficient accuracy by the formula:

$$L_{a+r} = {}^{a}\left\{\left(\frac{T_p}{100}\right)^4 - \left(\frac{T_a}{100}\right)^4\right\} + \delta\ (T_p - T_a)^{1.23}$$

Mean temperature difference.

In practical heat transmission work the temperature difference varies throughout the plant, and it is necessary to calculate the mean temperature difference before any formulae can be used. Since the heat transfer at any point in the plant is proportional to temperature difference, the rate of change of temperature difference throughout the plant cannot follow a straight line law and therefore the arithmetical mean is incorrect. It is, however, easy to prove that the mean temperature difference is given by the formula: $\theta_m = \dfrac{\theta_a - \theta_z}{\log_e \dfrac{\theta_a}{\theta_z}}$

Here θ_m is the mean temperature difference, θ_a and θ_z the greatest and smallest temperature differences.

The calculation of this logarithmic mean is tiresome, but by the use of a graph, this calculation becomes simple arithmetic. Let $\frac{\theta_z}{\theta_a}=j$, then $\theta_m = \theta_a \left(\frac{1-j}{\log_e \frac{1}{j}}\right) = J\theta_a$

A curve is drawn on squared paper, giving the value of $\left(\frac{1-j}{\log_e \frac{1}{j}}\right)$, or J for every value of j. θ_m is then obtained by multiplying J by θ_a.

Flow of fluids.

When a fluid flows through a pipe, it may move in parallel lines or in eddying motion, i.e., in *stream line*, or in *turbulent* flow. It is obvious that the nature of the flow must have a considerable effect on heat transmission in such cases. In stream line flow, convection is nearly absent, while turbulent flow becomes a sort of forced convection. In fact, nearly the whole of the heat transmission takes place by convection. In many industrial operations, and especially in heat transmission, care is taken that turbulent flow only takes place, and stream line flow is avoided. On the other hand, in some industrial operations such as filtration, separation, etc., stream line flow is essential.

In a given pipe with a given fluid, the change from stream line to turbulent flow takes place at a fairly definite velocity, called the critical velocity. The value of this critical velocity will, therefore, be the criterion of stream line and turbulent flow. This criterion is conveniently stated by the equation: $\frac{dv\rho}{\eta}=2000$. Where d=diameter of pipe; v=velocity of fluid; ρ=density of fluid; η=viscosity of fluid. The value 2000 is not exact and depends on the character of the surface of the pipe and its form. The equation is correct for any system of consistent units, and is true for both gases and liquids.

Now the velocity of the fluid is not uniform across the pipe section. In the case of turbulent flow, the average velocity is about .8 times the velocity at the centre of the pipe, but in stream line flow a steeper curve, a parabola, in fact, is obtained and the average velocity is half the maximum.

Since the surface of the pipe is tangential to the velocity curve, there must be a film next this surface of zero velocity, which, on account of the poor conductivity of the fluid, influences the rate of heat transmission very adversely. It is convenient, in discussing such problems, to conceive of fluid flowing over a heating surface, but separated from it by a stagnant film more or less thick, which is constantly being comminuted on its surface and mixed with the main body of flowing fluid. The resistance to the flow of heat will be determined in this way by the thickness of the stagnant film.

The flow of heat between two fluids separated by a metal partition, therefore, will be a doubly complex matter. The temperature change from fluid to fluid is made up of at least three parts: the temperature fall through the hot fluid film; the drop through the metal partition by conduction, and the fall through the cold fluid film to the mass of cold fluid. An estimation of the resistance of such films under practical conditions should give all the data for the total resistance or the "over-all coefficient of heat transfer."

The "*over-all*" coefficient of heat transfer is usually defined as the number of calories passing through a partition 1 sq. metre in area, when the temperature difference on either side of it is maintained at 1° C. The conditions under which the coefficient is determined must be stated in full, in order that corrections may be made in applying the coefficient to special purposes. These conditions would include the character and velocity of the fluids; whether they are boiling or non-boiling; the character of the metal partition; its thickness, form, quality of surface, etc.

For the purpose of comparison, such coefficients are usually determined or stated in relation to copper partitions 1mm. thick, and it is not difficult to obtain suitable factors for other metals of any thickness.

Although it has been stated that the temperature drop in a heat transmission problem consists of three parts, there is little doubt that there are really five, and that surface resistances of the metal partition are involved as well as film resistances. In the transmission of heat by radiation, the quality of surface has a very important influence and a slightly tarnished copper surface will radiate four or five times as much heat energy as a polished surface, and it is extremely likely that in all problems of heat transmission this quality of surface must enter in the same way. Experimental work in the author's laboratory has proved that in heat transmission from permanent gases modifications of the surface conditions may increase the heat transmission by as much as 75 per cent., and in heat transmission to liquids, a similar effect (16 to 30 per cent. increase) is obtained. A difference in surface conditions, then, apart from questions of roughness, may affect heat transmission considerably.

It is useful to be familiar with rough comparative values of the over-all coefficients of heat transfer, and such rough knowledge would have saved the country in recent years, especially during the war, a considerable sum of money.

With the fluid flowing at about 1 metre per second, the coefficient of heat transfer from hot permanent gases to non-boiling water through copper 1 mm. thick is roughly 20 calories per sq. metre of surface per hour per 1° C. of temperature drop; from hot water to colder water the coefficient may be about 600; while from steam to water a value of 1,000 is obtained. If the transmission takes place to boiling water, the value is increased greatly and may be twice or three times that stated above.

Again, the flow of heat through the film on either side of a heating surface is made up to two parts; that due to conduction and internal diffusion and that due to eddying motion which brings fresh particles into contact with the stationary layer. The determination of such film coefficients is obviously very difficult and the experimental results are very confusing and involved. Useful estimates can, however, be made in many cases.

For permanent gases in turbulent flow in metal tubes Nusselt gives the equation[9]: $k_1 = b\,(v_1\,\rho_1)^{.786}$ where k_1 (film coefficient) = calories per sq. metre per m., per °C. temperature drop; v_1 = velocity of gas in m. per sec.; ρ_1=density of gas in kilos per c. m.; b=5.77 for air; 4.77 for carbon dioxide; 15.4 for coal gas; 10.8 for superheated steam; For liquids flowing in clean copper or brass tubes[4]: $k_1 = \frac{1.94\ K}{d}\left(\frac{dv\rho}{\eta}\right)^{.8}$ Where k_1=calories per sq. m. per °C. per hour; d=diameter of pipe in metres; K=conductivity of the liquid (sq. m. per °C. per hour); $\frac{dv\rho}{\eta}$=criterion of flow.

In estimating the heat transmission in pipes which are not circular, it is usual to substitute in the formulae four times the hydraulic mean depth for the diameter—the hydraulic mean depth is the area of the conduit divided by the perimeter of the heating surface.

Where a condensing vapour is the fluid in question, there is little knowledge of the film coefficient but it is usually assumed to be of the order of about 280; it increases, however, with the velocity of the fluid and is modified by pressure, thermal conductivity, etc. The film coefficients between liquids and metal are almost unknown, and until more experimental work has been done it will not be possible to carry the analytical discussion much further.

Owing to the absence of data, the application of strict scientific analysis to the problems of heat transmission is usually difficult, and empirical methods become more useful. In 1916, Hedrich and Fessenden put forward the "log.-log." formula for the transmission of heat from gases to water in the flues of boilers, etc.[7]

If x is the distance apart of two points in a flue where the absolute temperatures are T_1 and T_2 and t be the temperature of the metal wall of the flue, then the following relation holds:

$$\text{log.-log.}\ \frac{T_1}{t} - \text{log.-log.}\ \frac{T_2}{t} = Mx.$$

M is a constant for a given set of conditions and is obtained for any case by solving other equations involving the weight of gas flowing per hour, and the size and shape of the flue. The results obtained by this method are very satisfactory and useful.

The over-all coefficient, however, which is of general utility, is used by all manufacturers, and is obtained from experimental work on plants in actual use. It is necessary, however, to estimate such over-all coefficients as a preliminary to design when data for similar plant are not available. An extremely simple case is that for transmission of heat from flue gases under conditions of natural draught to a liquid through copper 1 mm. thick: in this case, $k = 21$ F.G., where k is the over-all coefficient in calories per sq. m. per °C. temperature drop; F is a factor for the metal which may be calculated in comparison with copper 1 mm. thick, using the same film resistances: G is the factor for the liquid, which, in the case of water is 1, and in the case of salt solutions of, say, 10 per cent. strength, .9.

Similarly, for steam pans when the steam supply pipes are of ample size, k=1,600 F.G.

Hausbrand[3] gives a formula for the transference of heat from saturated steam to bring water by means of steam coils (within certain limits of length). $k=\frac{1,200}{\sqrt{dl}}$ where d and l are the diameter and length of the coil in metres. Other formulae, from which over-all coefficients may be obtained for heating, cooling, condensing, etc., will be found in standard works on the subject, [3, 4, 5, 6] and are not too inaccurate for practical application, or at any rate for first designs. As a rule, however, such estimated over-all coefficients may need considerable correction, after practical test, with a view to their application to competitive manufacturing design.

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Chapter 2.

PRINCIPLES OF WASTE HEAT RECOVERY IN INDUSTRY.

By J. W. Reber, M.I.Chem.E.

Until recent years fuel and labour were comparatively cheap, and the efficiencies of industrial furnace and heat utilising plants were not taken into consideration to the extent that they are to-day. During recent years, however, the costs of fuel and labour have increased very considerably, and every engineer or chemist in charge of " heat plants " is striving to reduce his fuel bill by increasing the heating efficiency of his plant, and by utilising the available surplus or waste heat in the most suitable way for his manufacturing process. Fuel economy and higher furnace efficiency generally increase the rate of working, and thus the increased output of material treated per " man-shift " decreases the cost of labour.

The surplus amount of sensible heat in the products of combustion depends entirely on the temperature of the furnace operation. The temperature of combustion or flame temperature, depends on the nature and the composition of the fuel, as well as the amount and temperature of the combustion air. If combustion takes place with the theoretical amount of air required, the resultant combustion products contain the maximum amount of carbon dioxide gases corresponding to the nature of the fuel burned, and in consequence the resultant temperature of combustion, usually called the theoretical flame temperature, represents the maximum temperature obtainable.

In direct-fired furnaces, the amount of air in excess of the theoretical requirements is as much as 100 per cent., and very often far higher. With up-to-date gas producer installations, making either hot or cold gas, but of uniform composition, it is possible to regulate the combustion air to practically the theoretical amount. The combustion products must necessarily leave the furnace at a temperature somewhat higher than that required for the actual heat process. With the amount of fuel burned under the above conditions, and with combustion gases containing the maximum amount of carbon dioxide consistent with the nature of the fuel used, the furnace would be operated at the highest possible efficiency. This result, however, is based on the assumption that heat losses by radiation round the furnace chamber are kept within reasonable limits, by correct design and suitable insulation.

The amount of sensible heat in the combustion products after leaving the furnace proper is called surplus or waste heat. The percentage of this waste heat is practically inversely proportional to the difference in temperature between the waste gas products and the theoretical flame temperatures. Unskilled furnace operation, variation in the composition of the fuel burned, and excess combustion air, all increase the amount of waste heat losses, reducing thereby the furnace efficiency.

The quantity of heat given up by the combustion gases in the furnace chamber is the product of their quantity, mean specific heat, and the difference between the temperature of the combustion products at the time when the actual combustion takes place, and when they are leaving the furnace. In other words, the maximum efficiency of heat absorption in the furnace cannot exceed the following fraction:—

$$\frac{\text{Total heat content of combustion} - \text{Total heat of waste gases}}{\text{Total heat content of combustion.}}$$

An increase of the above efficiency can only be obtained by increasing the flame temperature of combustion, or by decreasing the temperature of the waste gases. The former temperature can be increased by correct regulation of the combustion air and by preheating the air and the gaseous fuel, if this is being used. The temperature of the waste gases can be reduced by the recovery of their sensible heat in one of the following three devices:—(1) Recuperators; (2) Regenerators; and (3) Waste heat boilers.

The advantages and disadvantages of each of the above methods of waste heat recovery are briefly considered in this chapter, though it does not represent an exhaustive theoretical study of the above subject, and should only be regarded as a general summary of the practical side of waste heat recovery plants.

MEAN SPECIFIC HEATS AT CONSTANT PRESSURE PER 1,000 CU. FT. OF GAS PER 1° F. DIFFERENCE IN TEMPERATURE TO T° F. IN B.TH.U.'S.

Temperature °F.	Carbon Dioxide CO_2.	Water Vapour H_2O.	Oxygen, Nitrogen, Air, Carbon Monoxide.
32	24.729	23.172	19.435
212	25.539	23.234	19.559
392	26.535	23.359	19.684
572	27.532	23.421	19.808
752	28.404	23.546	19.933
932	29.089	23.725	20.057
1,112	29.712	23.857	20.182
1,292	30.335	23.982	20.307
1,472	30.958	24.231	20.431
1,652	31.456	24.542	20.556
1,832	31.830	24.791	20.680
2,012	32.204	25.041	20.805
2,192	32.453	25.352	20.929
2,372	32.765	25.726	21.054
2,552	33.014	26.037	21.179
2,732	33.388	26.411	21.303
2,912	33.699	26.785	21.428
3,092	34.010	27.283	21.552
3,272	34.259	27.781	21.677
3,452	34.509	28.342	21.802
3,632	34.633	28.965	21.926
3,812	34.758	29.588	22.051
3,992	35.007	30.211	22.175
4,172	35.256	30.834	22.300
4,352	35.381	31.456	22.424
4,532	35.505	32.142	22.549
4,712	35.630	32.827	22.674
4,892	35.755	33.512	22.798
5,072	35.941	34.197	22.923
5,252	36.066	34.945	23.047
5,432	36.190	35.692	23.172

EXAMPLE: The amount of heat required to raise 1,000 cubic feet of CO_2 gases from 32° F. to 212° F. would be $(212 - 32) \times 25.539 = 4597$ B.Th.U.,

RECUPERATORS.

In a recuperator the products of combustion pass continuously along one side of a partition wall and the heated medium, air or gas, passes continuously along the other side, *i.e.*, a recuperator is a continuous heat interchanger.

The separating wall, through which the heat is transmitted mainly by conduction, is built up from bricks, tiles or special hollow blocks, made of refractory material or of metal tubes. The metal recuperator has been adopted mainly for low-temperature work, especially for preheating the combustion air for boiler firing. For higher temperatures, metals of a greater capacity of heat resistance, such as calorised iron, chrome steels and nickel chromium alloys are being used in recent years. The high initial cost of these latter types of recuperators has, however, prevented their adoption on a large scale, although they incorporate practically all the requirements which are the basis of an ideal recuperator. The outstanding features of such a recuperator are: compact construction; the material employed should be non-porous and must possess a high thermal conductivity; the relationship of heating surface to the weight of the gaseous medium flowing through the tubes should be high, involving narrow flues. This latter should be easily accessible for cleaning. In view of rapid heat transmission, the partition walls should be comparatively thin, but of sufficient mechanical strength to prevent leakage through joints and cracks caused by unavoidable expansion and stresses. Shallow flues, although very suitable from a heat transmission point of view, have higher frictional loss, requiring an increased chimney draught, which again facilitates leakage and dilution.

In spite of the fact, that the manufacture of refractory material has been placed on a scientific basis, it is practically impossible to satisfy all the above-mentioned requirements for an ideal recuperator by using firebrick material. There are the three following types of recuperators:—The parallel flow, the counter current and the cross flow type. Each has its special advantages, depending on the nature and design of the specific furnace.

For materials of relatively low thermal conductivity such as refractories, the counter flow type of recuperator gives the highest temperature of preheat.

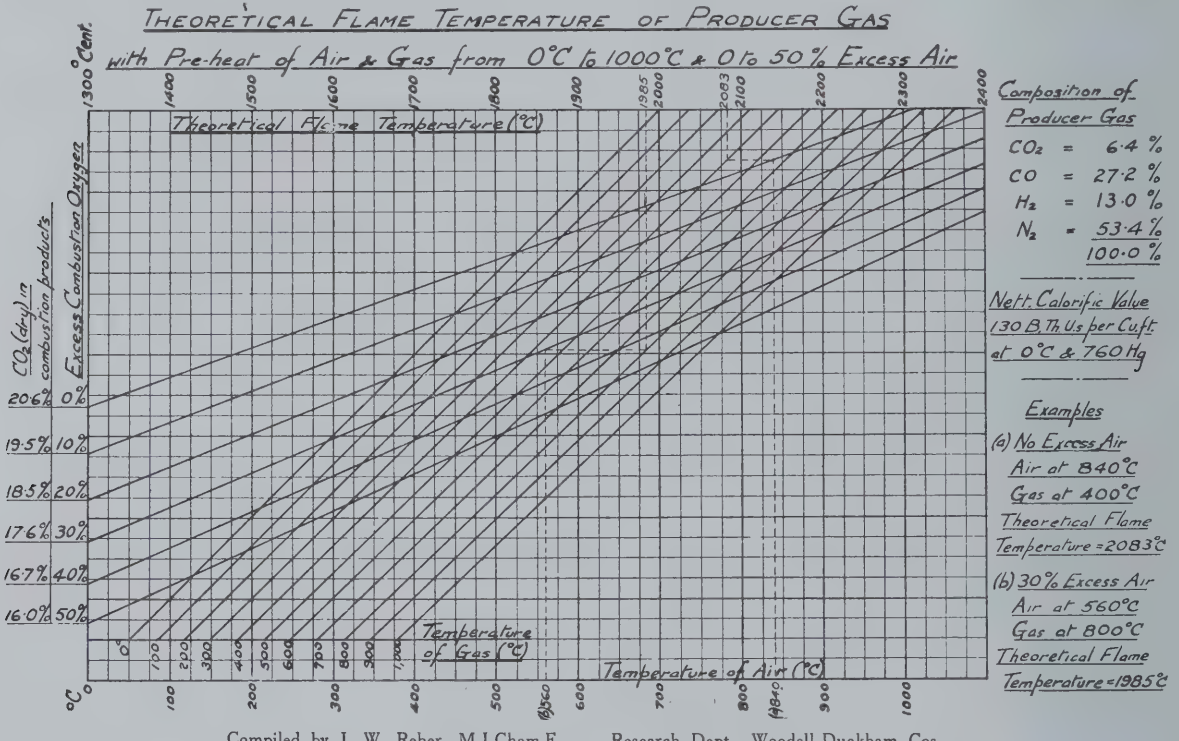
Heat transmission capacity.

In recuperators, heat is mainly transmitted by conduction and partly by convection. The maximum percentage which can be recovered by the preheat of combustion air when burning producer gas, is approximately 40—45 per cent. of the sensible heat entering the recuperator. In actual practice about 30 per cent. is recovered by the preheated air. The necessary heating surface depends on the extent of preheat and design of recuperator. The heat transmission factor increases with the temperature difference of the waste gases and air. R. Horning gives for refractory material a transmission factor of 2.2 B.Th.U.'s at 200° F., rising to 3.6 B.Th.U.'s at 1,500° F., difference in temperature per hour per 1 inch thickness per sq. ft. and 1° F. difference in temperature. In actual practice this factor is found to be about 1—1.5 B.Th.U.

From the knowledge of the temperature drop, due to the heat abstracted from the waste gases, as well as the volume or weight of the air and gases flowing per unit of time, including the extent of the preheat, the required heating surface can be approximately calculated, after due allowance is made for the variation of the heat transmission factor.

Collection of flue dust, short circuiting caused by leakage, and especially the meagre knowledge of reliable heat transmission factors, makes a precise calculation from a furnace designer's point of view, practically impossible. Most of the " data " published consists of empirical formulae, containing one or more variable factors, or coefficients, the exact values of which are not definitely established up to the present time and will give plenty of scope for future research work. Actual results obtained from tubular firebrick recuperators, with a temperature of the waste gases entering the recuperator at about 1,800° F., a preheat of the air of about 1,650° F., the necessary heating surface required was found to be 300—350 sq. ft. for a mean temperature difference of 500° F. of gas and air per 100lbs. of coke burned per hour in the producer of the furnace. The thickness of the partition walls between gas and air flues was about $1\frac{1}{4}$ inch. The advantages and disadvantages of recuperators, as well as their suitable adaptation, will be described further.

This type of waste heat recovery apparatus consists either of two or four brick chambers per unit, filled with chequer brickwork, according to whether only air, or both air and gas are preheated. The waste gases, as heating medium, and air, or air and gas to be heated, flow alternately through one or a pair of chambers in opposite directions. The chequer brickwork alternately absorbs heat from the waste gases and gives it up again to the air or air and gas during the next reversal period, which usually takes place every 20 to 30 minutes, according to the operating conditions of the specific furnace. These reversal periods necessitate a reversion of flow of the flames in the furnace proper, or as in the case of muffle furnaces, carbonising plants, coke ovens, etc., a change of flow of the combustion gases in the heating



Compiled by J. W. Reber, M.I.Chem.E. Research Dept., Woodall-Duckham Cos.

FIG. 1.

flues. This intermittent action of heat regeneration involves the provision and working of change-over valves. The efficiency of heat recovery of regenerators, of correct design, is high, the heat being transmitted from the chequers to the heated medium during the preheat period, partly by convection, but principally by radiation. According to the Stephan Bolzmann's law the heat transmitted by radiation is proportional to the fourth power difference of the absolute temperatures of the radiating and absorbing materials. During the waste gas period, the sensible heat of the waste products is taken up by the chequers mainly by conduction. The efficiency of heat transmission in regenerators depends to a large extent on the time contact; on the area of the exposed heat absorbing and heat emitting surface, and further, on the capacity of heat conductivity of the chequers. In well-designed regenerators, the temperature difference of waste gases and preheated air during one reversal period, is on an average 80—100° F. The theory of heat transmission in regenerators is of a very complicated nature, in fact, most of the data available is entirely empirical, and the deductions made by various investigators are very often at variance. Furnace design has developed mainly on lines indicated by years of practical experience and the knowledge accumulated by firms building furnaces is rarely, if ever, published.

Comparison of methods of regeneration.

Each of these two types of heat recovery has its advantages and disadvantages. The adoption of either depends to a very great extent on the heat requirements of the specific furnace. The recuperator,

although not so efficient as the regenerator, is a continuous heat interchanger, whereas regenerators work intermittently. The former, requiring practically no attention, is more suitable for smaller furnaces, especially in cases where the combustion temperatures required do not exceed 2,500° F. The recuperators built with refractory material require more space than regenerators. Operating difficulties caused by flue dust collection, cracks, leakage and dilution, can never be entirely eliminated in recuperators, even when the utmost care is taken in their design and construction.

These difficulties do not exist to the same extent in regenerators, although during the reversal period a certain amount of air or fuel gas is passed direct to the flues, and cooled waste gases are returned to the furnace; the resultant loss in thermal efficiency of the furnace is, however, generally below 1 per cent.

Large furnaces operating under very high temperature conditions, are mostly of the regenerator type and will continue to be such until a suitable material of high heat conductivity and high mechanical strength is available for recuperators.

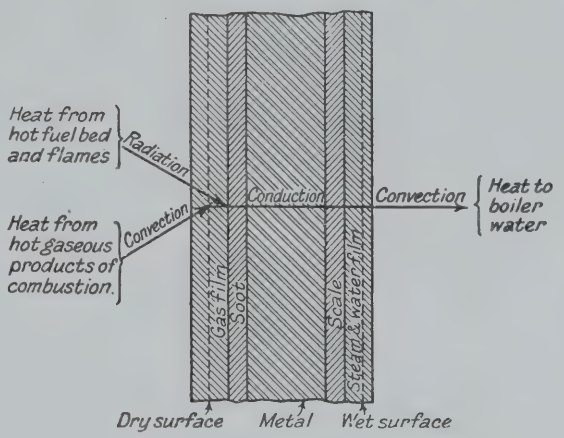


FIG. 2.—*Diagram showing Method of Heat Travel.*

It has already been mentioned that the amount of heat recovered by the preheat of one or both of the combustion media increases the total heat impact to the furnace, raising thereby the calorific intensity of the fuel used. Besides the resultant saving in fuel, further important savings may be emphasised. Amongst these are increased uniformity of furnace temperature, reduction loss of material due to oxidation, increased uniformity of product, and in most cases increased production due to higher flame temperatures.

Fig. 1 indicates the theoretical flame temperatures for various preheats of air or coke-producer gas, or both, up to 1,000° C., without and with excess combustion air. Two examples are indicated in dotted lines for various preheats of air and gas, one with theoretical combustion, and the second example with 30 per cent. excess air. The true flame temperatures are about 75—80 per cent. of the theoretical values.

WASTE HEAT BOILERS.

The generation of steam by the utilisation of the waste or surplus heat from industrial furnaces has been in practice in the iron and steel industry for over fifty years. Early waste heat boiler installations gave indifferent results, the size of the boilers being out of proportion to their steam raising capacity. The evaporation per unit of heating surface and the thermal efficiency of the boilers were low, but the results obtained have led the way to present-day improvements.

Besides the extensive use of waste heat boilers in the iron and steel industry, waste heat recovery for steam generation has been adopted in connection with carbonising plants, cement and lime kilns, glass tanks, gas engines, etc. In many instances the overall heat efficiency of the furnaces has been raised in consequence from 20 to 50 per cent.

Gas works' practice of to-day has accepted waste heat boilers as a standard design for carbonising plants.

Types of waste heat boilers.

Waste heat boilers are either of the water or fire-tube type, each of which has its advantages and disadvantages. In many cases the type of boiler installed depends on the preference of the engineer. From a thermal efficiency point of view, the fire-tube boiler is preferable to the water tube-boiler. This statement has been proved amply by the practical results obtained. Direct-fired water-tube boilers give

splendid results, due to the fact that about 70 per cent. of the heat is transmitted by radiation. This percentage of evaporation takes place in the first rows of tubes exposed to the radiant heat of the furnace, resulting in a rapid and positive water circulation in the boiler.

In waste heat boilers utilising waste heat at comparatively low temperatures, the heat transmitted by radiation is extremely small, and the heat transmission takes place mainly by conduction and convection. The two most important factors which determine the overall efficiency of a waste heat boiler are a high rate of heat transmission and at the same time a minimum back pressure thrown by the tubes. Both of these are dependent on mass velocity, generally expressed as follows: $\frac{W}{a}$ where W is the weight of gas in pounds per hour and a the sectional area of the gas passage in square feet. As the draught loss through the tubes varies as the square of the velocity, there must obviously be an economical limit between the size of boiler, total evaporation, and the power required by the suction fan. On account of the lower friction loss in fire-tube boilers for a given mass velocity, the latter can be raised in the fire-tube type, resulting in an increased rate of heat transmission. In other words, under similar conditions, fire-tube boilers properly designed, will give a higher evaporation per unit of heating surface than water-tube boilers although the back pressure by the two boilers may be identical. Waste heat boilers for small furnaces and carbonising plants up to 40 tons of coal per day, are mostly worked by natural draught. Larger installations, where the aim is the highest possible evaporation, forced draught must be employed, regardless of the type of boiler.

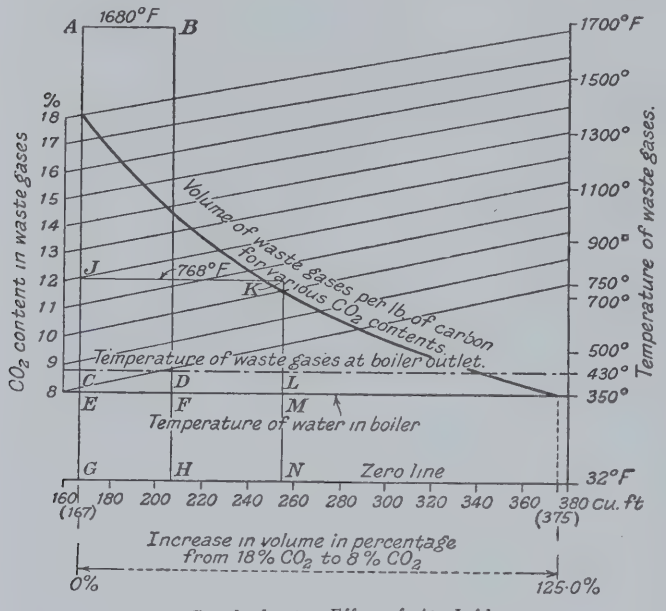


FIG. 3.—*Graph showing Effect of Air Infiltration.*

With boilers of the water-tube type in brick settings, air infiltration through cracks, loose joints and ill-fitting covers, etc., always takes place, and an increase of 10—20 per cent. of the original waste gas volume entering the boiler is nothing unusual. This increased volume requires a higher pull, and therefore a higher fan power. The various remedies against infiltration in the form of pointing, paints or cement, have not been successful. Steel casing as an alternative increases considerably the cost of installation. Generally, water-tube boilers are easier to keep clean, both on the water and gas side.

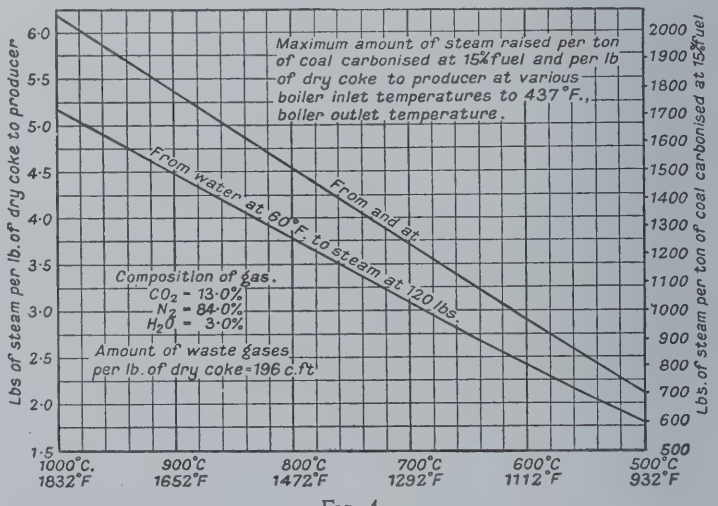


FIG. 4.

However, with suitable feed-water treatment prior to use, and a suitable type of dust-blower, there should be no difficulty in keeping a fire-tube boiler in good working condition. Each waste heat boiler proposition must be worked out solely on its own basis.

The efficiency of a waste heat boiler is a matter of correct design, based on the temperature composition and volume of the available waste gases. It may be of interest at this point to explain briefly the heat interchange between the hot gases and the water in a boiler. There are three modes of heat propagation, namely, radiation, convection and conduction. Each of these three modes of heat propagation is entirely distinct from the other two, and the laws governing each differ essentially. In the process of heat absorption by direct-fired boilers, all of these three modes are active, either in combination, in which one predominates more or less, or acting singly in successive parts of the path of heat travel. This is shown diagrammatically in Fig. 2. In waste heat boilers the amount of heat transmitted by radiation is very small, owing to the low temperatures involved.

It will be seen from Fig. 2 that the heat contained in the gaseous products in the form of sensible heat is imparted to the dry surface of the heating plate by convection from the hot moving gaseous products. When the heat reaches the dry surface, it changes its mode of travel, and passes through the flue-dust coating, metal and scale to the wet surface purely by conduction. From the wet surface of the plate, the heat is carried into the boiler water mainly by convection.

The laws of heat transmission in steam boilers by convection have been laid down by Professor Osborne Reynolds in his classic paper, read before the Literary and Philosophical Society of Manchester in 1874. These laws have formed the basis of all the later important investigations carried out by Percy, Stanton, Nicholson, and Dalby, the results of which may be summarised as follows:—

> " Convection of heat from one plane to another is a process of continuous interchange of position between cooled particles (molecules) of gas next to the heat absorbing surface and hotter particles within the body of the gas. The quantity of heat imparted to a unit of area of dry surface of the boiler tube depends on the rate at which these particles of gas exchange.
>
> " Conduction of heat is the process by which heat flows from a hotter body to a cooler one, when the two bodies are in contact. Conduction implies no visible or mechanical motion of different bodies or different parts of the same body, but implies direct contact. In a boiler, the heat passes by conduction from the particles of hot gas that touch the flue-dust coating if existent, into the coating, and then through the metal and the scale (if existent) into the particles of water next to the scale. These particles of water absorb heat until they change into small bubbles of steam which are carried away by the circulation of the water. Since the heat in these steam bubbles is taken from the heating plate through the water into the steam space by mechanical or visible motion, it is said to travel by convection."

The low rate of heat transmission in the present boilers lies in the transmission from the hot gases to the dry surface of the tube. The metal itself, even with a moderate coating, is capable of conducting enough heat to the water with a comparatively small part of the total temperature drop between the gases and boiler water. On the inside of the boiler tube, the water, on account of its high heat capacity, readily takes the heat from the surface of the tube so that the temperature drop usually needed is very small.

In waste heat boilers, the heat imparted by convection is the larger part of the total heat the boiler receives, therefore increasing the rate at which heat is imparted to the heating surface by convection causes a nearly proportionate increase in the rate of steam production. The rate of heat transfer at high mass velocity varies almost in proportion to the mass velocity, and therefore by increasing the velocity by reduction of the number of tubes, a greater rate of heat transfer by convection is attained.

It is by adopting a high velocity factor that locomotive and marine boilers are able to produce steam at two or three times the rate customary with stationary boilers. In these two types of boilers double or triple capacity is obtained by forcing over their heating surfaces two or three times the weight of gases at two or three times the velocity.

It has also been found, both as the result of experiments, and by theoretical considerations, that more heat can be abstracted from the same weight of gas if the length of the gas passage is increased or the cross section of the passage is reduced; the second condition must always include the reduction of the depth of the gas stream, called the hydraulic mean depth. Both these conditions increase the number of contacts the particles of gas make with the dry surface.

Obviously, abstracting more heat from the gases means higher boiler efficiency, and since the length and the cross section of a gas path is really the arrangement of the heating surface with respect to the gas stream, one may say that the efficiency of the boiler depends on the arrangement of the heating surface with respect to the flow of gases.

The correct adoption of the above factors, namely, velocity of waste gases, diameter and length of tubes, is essential in the design of waste heat boilers.

There is another important factor which influences the efficiency of waste heat recovery. This is the CO_2 content of the waste gases. The volume of these gases is in inverse proportion to their CO_2 content, which varies usually from 16 per cent. to 10 per cent. In some cases where the boiler is attached to a carbonising plant which has been working for some years, the CO_2 content is found to be as low as 8 per cent., owing to leaky recuperators and leaky waste gas flues. Although the total heat content of the waste gases entering the boiler will be the same whatever the extent of air infiltration, it will be seen that the increased volume of gases lowers the overall efficiency of the boiler, and will necessitate more heating surface and fan power.

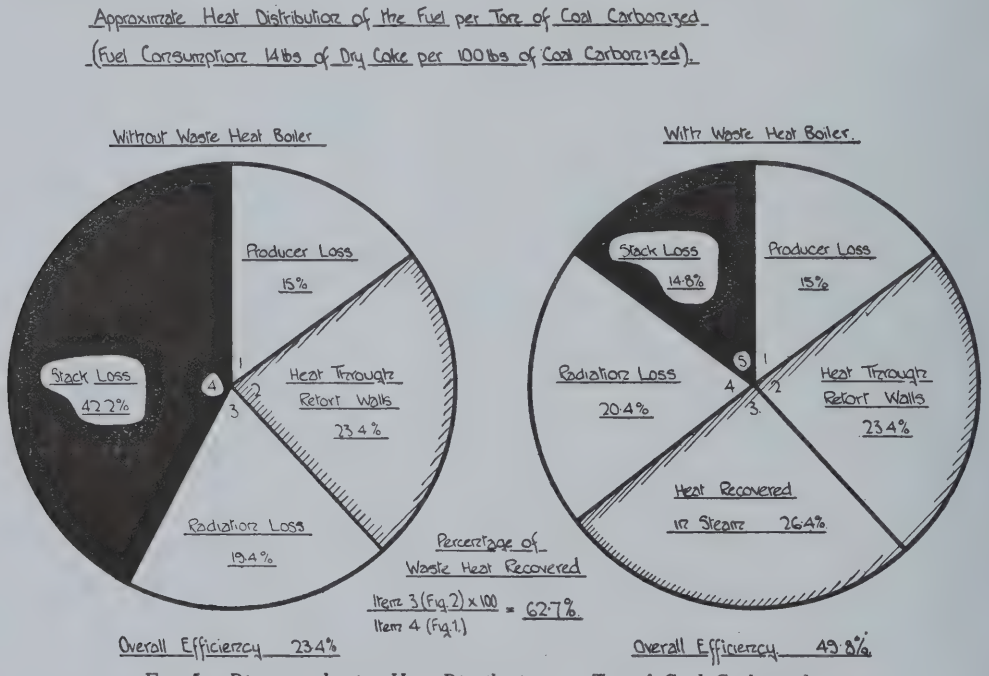


FIG. 5.—*Diagram showing Heat Distribution per Ton of Coal Carbonised.*

Heat losses due to infiltration.

The heat losses due to infiltration are shown by Fig. 3. The ordinate on the left side of the graph represents the CO_2 content of the waste gases, the abscissa represents their volume in cubic feet per pound of carbon gasified in the producers for CO_2 contents from 18 per cent. down to 8 per cent. The ordinate on the right side of the graph represents the temperatures in degrees Farenheit corresponding to every CO_2 content, and these represent approximate conditions found in practice. In order to simplify the graph, the specific heat values have been taken to be constant at all temperatures. The total heat of the gases entering the boiler, for a CO_2 content of 18 per cent., is represented by the area of A B H G, G H lying on the line representing a temperature of 32° F. The equivalent area for the same heat content, but for a CO_2 content of 8 per cent., is represented by J K N G, G N also lying on the line representing 32° F. The line E F M indicates the temperature of the steam or of the boiler water, assuming that both the latter are at the same temperature. The temperature of the products leaving the boiler is shown by line C D L. This temperature has been taken to be 430° F. The heat represented by the areas E F H G and E M N G being below the temperature of the water in the boiler will not flow into the water, and therefore is not available for absorption.

The heat represented by areas A B F E and J K M E is available for absorption. The steam temperature has been taken at 350° F., which is equivalent to 120lbs. gauge pressure. The heat absorbed by the boiler in the first case is represented by the area A B D C and in the second case by the area J K L C. The percentage of the heat absorbed of the heat available for absorption represents the true boiler efficiency.

Taken as a percentage of the total heat entering the boiler, the amount of heat leaving the boiler will be about 24.3 per cent. for case No. 1, and 54.0 per cent for case No. 2, *i.e.*, the total heat efficiency of the plant, not taking into account any radiation losses, will be about 75.7 per cent. for a CO_2 content of 18 per cent., and only 46 per cent. for a CO_2 content of 8 per cent. The above two examples have been chosen to represent extreme cases, but they clearly illustrate the importance of keeping the CO_2 content as high as possible. Assuming equivalent temperatures of the waste gases at the fan inlet, the power required for case No. 2 would be about 11 times that for case No. 1 to overcome the back pressure thrown by the boiler tubes in a boiler of equal cross-sectional area and tube length.

The graph, Fig. 4, applies only to cases where, for a given CO_2 content, the temperature of the waste gases is identical with that given on the graph. In other words, a graph must be drawn out for each individual case.

CARBONISING PLANTS.

The following example illustrates a method of determining the amount of steam from the waste gases of a carbonising plant, working under the following conditions:—

Fuel consumption per 100lbs. of coal carbonised (dry coke) ... ... 15lbs.
Percentage in weight of fuel gasified as carbon 85%
CO_2 content of waste gases (moist) 13%
Temperature of waste gases—
(*a*) Entering boiler ... ... 1,432° F.
(*b*) Leaving boiler ... ... 432° F.

In order to calculate the available heat content of the waste gases, it is necessary to determine the volume of the latter. The molecular weight of any gas expressed in grams occupies 22.412 litres per gram-molecule at 0° C. + 760 mm. The English equivalent molecular volume is 359.03 cubic feet per pound-molecule at 0° C. + 760 mm. (N.T.P.). For approximate calculations 360 cubic feet per pound-molecule will be sufficiently accurate. In our example the waste gases contain 13 per cent. of CO_2 (including water-vapour), which is equivalent to 0.0333 × 0.13lb. of carbon. The volume of waste gases for the above example per ton of coal carbonised, will be as follows:—

$$\frac{2{,}240 \times 0.15 \times 0.85}{0.033 \times 0.13} = 65{,}840 \text{ or say, } 66{,}000 \text{ cubic feet.}$$

The mean specific heats of the waste gases at boiler inlet and outlet have been calculated from the mean specific heat in table previously given, and are as follows:—

At 1,432° F. = 22 B.Th.U.'s per 1,000 cubic feet.
At 432° F. = 20.9 „ „ „

Total heat content of the waste gases

(*a*) Entering the boiler = 66 × 22 × 1,400	2,032,800 B.Th.U.'s	100.0%
(*b*) Leaving the boiler = 66 × 20.9 × 400	551,760 „	21.6%
Amount of heat taken up by the water and lost in radiation	1,481,040 „	72.4%
Radiation loss (estimated)	70,040 „	3.4%
Heat taken up by boiler	1,411,000 „	69.0%

Or in lbs. of steam from and at 212° F. $= \frac{1{,}411{,}000}{970.4} = 1{,}450$lbs.

This represents the amount of steam which can be raised under the above conditions per ton of coal carbonised. The waste gas products from carbonising plants (not including regenerative coke ovens) are of a temperature range from 800—1,800° F.

The graph given in Fig. 5 gives the maximum amount of steam which can be raised per ton of coal carbonised for a fuel consumption of 15lbs. of dry coke per 100lbs. of coal carbonised, for a CO_2 content of 13.0 per cent., including water vapour, at various temperatures at the boiler inlet, and for a temperature of 437° F. at the boiler outlet.

The effect of waste heat recovery on the overall thermal efficiency of a carbonising plant is shown in Fig. 5 by an approximate heat balance of a retort installation working without, and in conjunction with, a waste heat boiler.

T. Hardie gives the thermal efficiency of a modern carbonising plant at 73 per cent. with, and at 31 per cent. without, waste heat boiler.

On plants of recent construction and modern design, as much as 5lbs. of steam by waste heat recovery is produced per pound of coke charged into the producers, being almost equivalent to the evaporation obtained per one pound of coke burned in many direct-fired boilers. It is very significant that notwithstanding these results, there is practically no increase in the fuel consumption for heating the retorts.

The enormous saving in capital by waste heat recovery will be realised by the following paragraph.

Assuming that the annual amount of coal carbonised in gas works in Great Britain amounts to 15 million tons, the possible saving to be effected by waste heat recovery would be approximately £3,000,000. The amount of steam generated in this manner on gas works in this country would be sufficient to generate almost one-third of the electricity now generated in authorised power stations in Great Britain.

WATER GAS PLANTS.

Messrs. Humphreys and Glasgow, the well-known water gas engineers, are utilising the heat of the blow gases for the generation of high-pressure steam.

The available surplus heat during the blow period of the water-gas process is more than the amount required for raising the necessary quantity of steam for gas making and for driving the blower.

Recently the above firm have introduced a further improvement in their design.

Their automatic self-clinkering generator is water-jacketed and raises sufficient low-pressure steam for the requirements of the generator for gas making.

The amount of surplus steam from the waste heat boiler, working with the newest type of generator, and after due allowance is made for the amount required for driving the blower, can be taken at about 30lbs. per 1,000 cubic feet of water gas.

A further source of heat for steam raising in gas works provided with intermittent working retorts is available from the dry cooling of incandescent coke. Further, information on this method of steam raising will be found in Part IV. under "Gas Works' Coke," Chapter 3.

It may be safely stated that there is sufficient waste heat available in most of the existing gas works to raise all the necessary steam for the works requirements.

INDUSTRIAL FURNACES.

In the iron and steel industry there is a vast field for waste heat recovery.

From open hearth furnaces with waste gas temperatures at 1,200—1,500° F. the amount of steam generated per ton of ingot is about 1,100 to 1,500lbs. The saving effected expressed in terms of fuel required in coal-fired boilers is equivalent to not less than 250lbs. of coal (at 11,000 B.Th.U.'s per lb.) per ton of ingot.

From reheating furnaces, 2 to 5 pounds of steam can be obtained per pound of coal burned. Puddling furnaces yield about 2lbs. per pound of coal. Copper refining furnaces with waste gas temperatures of 1,400—2,200° F. are especially suited for waste heat utilisation. Cement kilns yield about 1,800lbs. per ton of burned cement, or 2.5—3.5lbs. of steam per pound of coal used as fuel.

Exhaust from gas and Diesel engines.

Exhaust gases from gas and Diesel engines supply a further source of waste heat, yielding about 1—2lbs. of steam per B.H.P. The following table shows the heat balance of a large gas engine:—

Heat converted into mechanical work	27%
Heat to cooling water	30%
Heat lost by radiation and conduction	5%
Heat in exhaust	38%

Of this 38 per cent., about 28 per cent. can be recovered in the form of steam.

Exhaust Steam.

The utilisation of exhaust steam for steaming producers and gas retorts, preheating boiler feed water, heating of works, offices, etc., as well as for drying purposes in chemical plants, represents a further source of waste heat recovery.

The utilisation of surplus blast-furnace and coke-oven gas, although surplus heat, does not come under the heading of waste heat recovery in the true sense of the expression. These are, however, closely linked up with the general heat recovery problems of the steel industry.

CONCLUSIONS AND RECOMMENDATIONS.

A brief description has been given of the various methods of waste heat recovery in industry. The most suitable application of these methods, either alone or in combination, depends to a great extent on the type of plant, and the question should first be considered from the point of view of the heat economy of the works as a whole. The extent to which preheating is economic and desirable, either in recuperators or regenerators, has been the subject of considerable controversy, but it should be possible to strike a happy medium between the proportions of the available waste heat to be used for preheating by regeneration and steam production.

Before the question of waste heat recovery in any form is considered, the greatest possible efficiency of the furnace itself should be secured. Perfect combustion, reduction of heat losses by good lagging and utilisation of the heat given off by radiation for the partial preheating of the combustion air, are some of the means by which furnace operation can be made more efficient.

Ideal furnace conditions such as indicated above would have the effect of reducing to a certain extent the degree of preheat at present required for the combustion media. Further, these improved conditions would increase the temperature of the waste gases, resulting in a higher efficiency in the heat recovery.

The efficiency of both regeneration and steam production could be improved by passing only a proportion of the combustion gases through the regenerators or recuperators and sending the remainder direct to the waste heat boiler. In this way, the size of both heat interchangers would be much reduced, while the efficiency of each would be considerably increased. An additional advantage resulting from this arrangement would be the reduced power consumption of the waste heat boiler fan, owing to the lower column of gases to be handled.

Every works of any importance should employ their own heat expert. During the last ten years, various industrial associations and concerns on the Continent have organised institutions of their own, purely for studying and giving advice on questions of heat economy. In order to get the full benefit of such research, it would be of great advantage to standardise internationally the method of testing heat plants, and, most important of all, the scientific data essential for the correct determination of heat balances.

Heat economy should be one of the subjects in the curriculum of all students of engineering. The great influence of waste heat recovery and of heat economy in general on the costs of manufacture has not yet been sufficiently realised, but it is a subject which from a national point of view, would amply repay further consideration and research.

Chapter 3.

STEAM ACCUMULATION.

By Stanley Hopkins.

Steam accumulation or thermal storage, i.e., storage of heat in the form of steam is an old engineering science, but it is only during comparatively recent years that it has been more generally adopted by engineers for use in industrial works. Some 60 years ago it was tried out and used in connection with fireless locomotives and a good many were and are still being manufactured. It was also used between the cylinders of engines, and later Halpin stored steam when it was available, during low demand periods and employed it for heating up the feed water which in turn was used when peak demands occurred. Rateau also designed a steam accumulator to take up the exhaust from engines—such as colliery winding engines. None of these systems was used to any extent in general industrial works and it was not until about 1913 that a greater development was indicated by Dr. J. Ruths, a Swedish engineer, and that the wider recognition of the valuable advantages in works where the conditions for its adoption were suitable, were appreciated and turned to real economic account. A large number of works in a variety of industries—collieries, iron and steel, textile, electric power station, pulp and paper mills, etc.—have now installed steam accumulator plants. The objects have been to give the steam consuming departments of a works all the steam wanted at any time and either to enable the boilers to be fired on an average load, or to take charge of the steam produced on an intermittent supply of heat—as in an iron and steel works—and hold it against consumers' demands. This means that steam accumulation is suitable in a works where both the steam production and the consumers' demand are intermittent or where one only is intermittent. The result, with a properly designed installation to suit the conditions ruling in a particular works, is the elimination of the bad effect of all variations in pressure and output of boilers, on all consumers in the works, whether high or low pressure.

The principle by which this result is secured is the storage of the heat in water during times of low load and its discharge in the form of steam during times of high load.

The degree of fluctuation which is met and has to be dealt with in industrial works is much wider than is generally known. A few instances representative of the industries stated and obtained by steam flow readings are given in the accompanying table.

If these figures are examined it will be noticed that, in order to meet the maximum demand, boiler heating surfaces far in excess of what would be required for a fully balanced load must be installed. With the levelling of the load by means of steam accumulation it is by no means an unusual event to cut out as much as 33 to 50 per cent. or more of the boilers operating in a works with variable loads.

Steam accumulation is obtained in works by:—

(*a*) Passing the steam, when available, into a separate insulated tank containing water at boiling point, allowing it to condense in this water under rising pressure and reversing the action during peak periods, that is allowing the steam to "boil off" from the water under falling pressure.

(*b*) Using the steam when the demand falls below the average for heating up the relatively cold feed water, storing the resulting hot water in a separate insulated vessel and using it for feed during peak periods. The water being at high temperature flashes off into steam with the addition of less heat in the boiler than feed water requires at normal temperature.

The system under (*a*) is the variable pressure accumulator and under (*b*) the constant pressure accumulator. Both systems are now receiving a wide application for use as an integral part of the steam plant and installations are now being made in this and other countries.

Variable pressure accumulator.

A form of variable pressure accumulator is the fireless locomotive, but it is not used as an integral part of a steam system in a works. The tank of the locomotive nearly filled with water is charged with steam by a hand-operated valve up to the pressure of the mother boiler. When the valve to the cylinders is opened the pressure is released, the thermal equilibrium of the water is upset and the steam boils off

and passes into the cylinders. The operating difference between this and the steam accumulators used in works is that the locomotive tank is entirely separated from the plant and necessarily works as a separate unit and tends to create peak loads, whereas in the factory plant the stationary accumulator forms part of the steam system and eliminates the effects of variations in the rate of steam production and consumption.

The Rateau accumulator is a variable pressure accumulator and falls under this heading. It is usually charged by the exhaust from colliery winding engines and discharged to a low-pressure turbine. This accumulator is limited by the operation of the engine and, owing to the small pressure range at which it is used—about 3 to 5 lbs.—can store only comparatively few pounds of steam and provide for a short period, in fact for only two or three minutes.

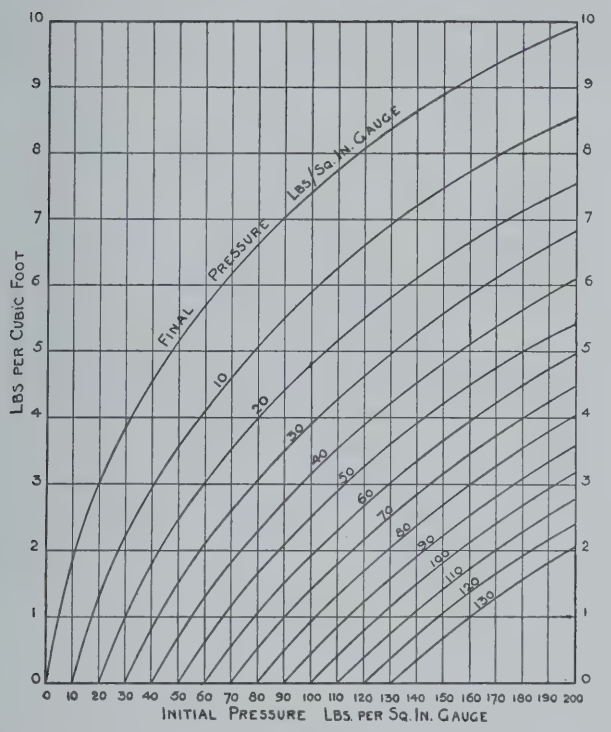


FIG. 1.

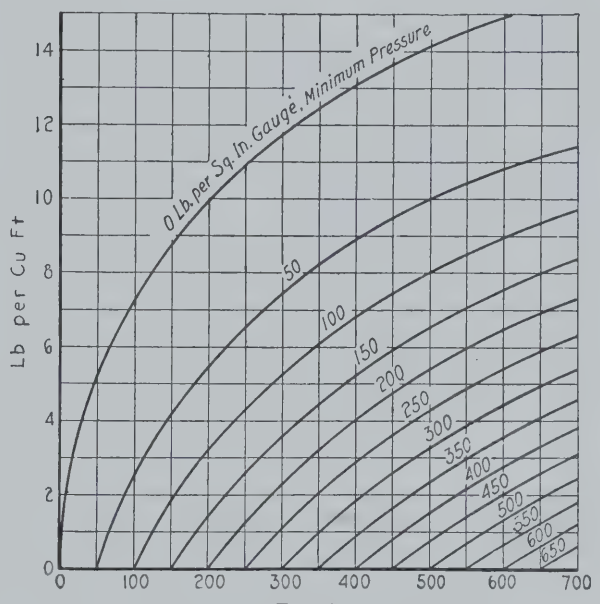


FIG. 2.

The variable pressure system can be used in all those many cases where there are users of steam at two or more pressures, or where there is an appreciable difference in pressure between the boilers and the consumers. It has received a substantial degree of support in industries where there are high and low-pressure steam consumers, the steam stored going to the low-pressure users at peak periods, thus relieving the boilers for the time being of their demand and allowing, if necessary, the whole of the boiler output at constant superheat to satisfy the demand of the high-pressure users.

As the accumulator is inserted between the boilers and the low pressure users, peak loads on these latter, of almost any magnitude, can be taken without the boilers being affected. The rate of steam leaving the boilers being constant neither the economisers nor the superheaters will suffer from overheating during periods of low steam consumption.

The size of accumulators of all systems is dependent on the magnitude of the variations to be bridged over, and no general statement can be made as to the size suitable for a particular works or boiler plant. For example, in the pulp and paper industry they may vary from say 5,000 lbs. of steam storage capacity to 50,000 lbs. and taking industries as a whole from a few hundred to 100,000 lbs. or more.

The amount of steam which can be stored in a given volume of water depends on the range of pressure available. The curves (by Backstrom) given in Figures 1 and 2 are now generally used for determining the amount of steam which can be stored per cubic foot of water for various pressure drops between 10 and 700 lbs. gauge. The following are examples:—

VARIATIONS IN CONSUMPTION OF STEAM. PERCENTAGE OF MAXIMUM DEMAND.

No.	Works.	Maximum Load, Lbs./hr.	Time.																				Mean.
			7	7-30	8	8-30	9	9-30	10	10-30	11	11-30	12	12-30	1	1-30	2	2-30	3	3-30	4	4-30	5	5-30	6	6-30	
1	Rubber works.	35,000	57	83	100	94	68	63	80	91	88	100	97	74	80	71	85	80	68	85	81	68	57	—	—	—	79
2	Colliery.	60,000	30	—	61	—	75	—	100	—	85	—	79	—	47	—	63	—	79	—	100	—	83	—	90	—	74
3	Brewery.	34,000	82	30	44	69	64	53	80	64	81	76	70	100	89	76	76	85	73	53	12	37	90	70	85	97	69
4	Leather works.	22,000	42	85	86	69	69	25	100	20	55	99	45	100	0	80	50	38	75	52	95	0	75	15	0	75	56
5	Carpet dye works.	24,000	53	100	86	61	55	80	83	48	73	44	0	0	0	87	41	55	64	29	59	44	55	41	3	57	52
6	Tin-plate works.	70,000	100	64	100	100	65	100	64	100	100	100	65	97	64	100	43	78	44	78	47	80	40	71	70	37	75
7	Soap works.	16,000	33	38	80	68	93	32	75	88	38	93	64	32	75	100	50	100	62	38	88	50	31	12	—	—	61
8	Sugar refinery.	190,000	68	84	71	66	72	76	42	36	51	50	48	60	58	57	73	77	84	68	66	52	73	58	52	100	64
9	Dyeing works.	16,000	20	100	28	66	83	65	100	38	47	55	0	0	93	40	73	40	72	47	33	29	0	—	—	—	49
10	Textile mills.	85,000	35	100	80	64	53	68	47	58	62	47	36	32	35	81	60	68	69	53	67	50	41	23	—	—	56
11	Pulp mills.	75,000	53	92	86	64	77	64	50	41	76	70	100	61	53	66	73	56	66	88	85	58	68	50	80	—	68
12	Iron & steel works	35,000	29	11	35	91	57	78	35	29	100	37	57	35	29	56	55	50	30	40	57	12	14	70	40	74	47

Drop in steam pressure.	Steam given off per cu. ft. of water in accumulator.
200 lbs. to 80 lbs.	4.0 lbs. approx.
200 ,, ,, 30 ,,	6.8 ,, ,,
100 ,, ,, 20 ,,	4.8 ,, ,,
80 ,, ,, 20 ,,	4.0 ,, ,,
60 ,, ,, 20 ,,	3.0 ,, ,,

It will be noticed that a considerably larger amount of steam can be stored per lb. sq. inch difference of pressure, in the lower ranges than in the higher, and on that account the minimum pressure of the accumulator is made as low as possible, consistent with the requirements of the low-pressure users.

It is frequently said that the boilers themselves are generally of sufficient capacity to meet the peaks in an industrial works, when a drop in boiler pressure is allowed. If a drop can be permitted this may be true and the method is, in fact, frequently practiced, but the amount of steam that can be provided by this means is comparatively small, and the advantages are nearly always lost by the disadvantages of the lowered boiler pressure and by the need for forced firing, to overtake the demand and get the pressure back to normal. If a Lancashire boiler has a water content of, say, 1,000 cu. ft. at normal water level, and is working at 120 lbs. and the pressure is allowed to fall at peak times to 100, it will be seen from the diagram that only 0.8 by 1,000=800 lbs. is available. With a boiler of this size it will represent only about six minutes steaming and if the strain continues losses occur, not only in forcing the boilers, but also owing to the works becoming short of steam and slowing up output. In the case of water-tube boilers the reserve of course is considerably less as the water contents are smaller, and where high pressures are used for power purposes a drop in pressure becomes serious. For example, if the boilers are working at 350 lbs. and a drop to 300 lbs. is allowed, about 1 lb. of steam per cu. ft. would be available. With the small drums necessarily used in high-pressure water-tube boilers, the small amount of extra steam which could be obtained would be of little value.

The proper method is to take these fluctuations away from the boilers and on determining their magnitude, to ascertain the pressure allowable in the low-pressure range and install a tank of the required capacity, *e.g.*, if the fluctuations above and below the average of the boilers, for a given time-period, which require to be taken up by the accumulator—after allowing a substantial margin—amount to, say, 10,000 lbs. of steam and the pressure drop available 100 to 20 lbs. gauge, the volume of the tank which is usually filled to 90% of its capacity will be $\frac{10{,}000}{4.8\times0.9}$=2,315 cu. ft.

In actual practice it has been found that for each ton of steam stored, the volume of the vessel varies between 350 to 1,100 cu. ft., according to the pressure drop available.

For the variable pressure accumulator, provision should be made for an equal and steady distribution of steam under

the water by suitable charging nozzles. The tank is made of steel with hemispherical ends and of a strength and construction to withstand, not only the maximum pressure at which it is working, but the great and sometimes rapid variations of pressure to which it will be subjected. Saddles or brackets are usually attached, and these should be equipped with roller bearings in order to meet contraction and expansion of the shell.

A covering of first-class insulating material is always used to prevent radiation losses, the usual standard demanded is that the material shall be of such a quality and thickness that the radiation loss shall be not more than 0.16 to 0.2 B.Th.U. per sq. ft., per degree Fahrenheit average difference of inside and outside temperature, per hour. A variable pressure accumulator approximately 13ft. by 50ft. with a pressure range of 170 to 50 lbs./sq. in. and storage capacity of about 20,000 lbs. steam, would on the above specification lose by radiation, when the mean outside temperature is 45° F., about 100,000 B.Th.U. per hour, i.e., about 85 lbs. of steam. Taking, say, 8 lbs. steam per lb. of coal, the cost will be only 8.5 lbs. coal per hour. Setting this against the coal saving always obtained by steam accumulation the loss by radiation is negligible.

The plants under the Ruths' variable pressure system are provided with an automatic oil operated overflow valve, so that when the pressure rises in the boilers due to the falling off of demand, this valve, which is of special construction, opens and instead of the safety valves on the boilers blowing off, the steam flows into the accumulator. When the demand comes on again and it meets the supply, the valve closes. When it is above the immediate capacity of the boilers, the pressure will fall and the valve controlling the steam supply to the low-pressure range—set at the pressure at which the low-pressure range is working—will open more and the steam flow from the accumulator under falling pressure, thus relieving the

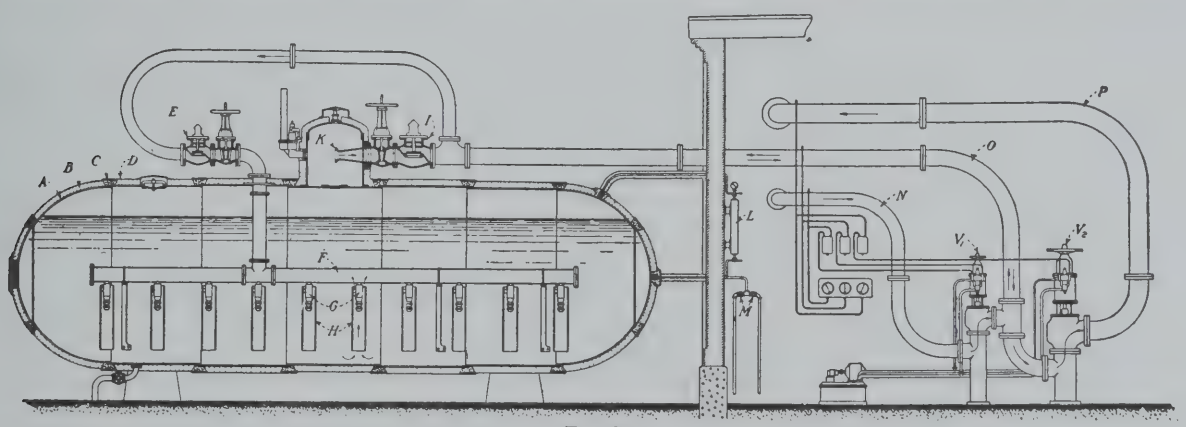


FIG. 3.

boilers of the necessity of making up the deficiency. If the accumulator is operating in conjunction with, say, a back-pressure engine, and is taking steam from its exhaust, the by-pass valve from the boiler main is provided with a combined action, so that steam can be passed from the boilers to the consumers if the accumulator happens to be discharged right down to its minimum pressure and also any surplus of steam due to falling off of demand is prevented by passing the excess for storage. A sectional line drawing of a plant under the variable pressure system combining an overflow valve is shown in Fig. 3. The non-return valve E admits charging steam to the steam distribution pipe F and the charging nozzles G which are provided with circulation pipes H. Through non-return valve I the discharge of the steam takes place. A de Laval nozzle K limits the maximum discharge of steam from the accumulator and prevents priming in case of breakdowns in the pipe system. A water level gauge L and feed valves M are provided for reading and the occasional adjusting of the water level in the accumulator.

The main N carries steam of high pressure and is connected directly to the boilers. All steam not used by the high pressure users is passed through valve V_1 to the accumulator line O. Valve V_2 works as a reducing valve, supplying steam to low-pressure consumers. When more steam is passed through valve V_1 than valve V_2 the excess will pass through pipe O, back-pressure valve E and into the water of the

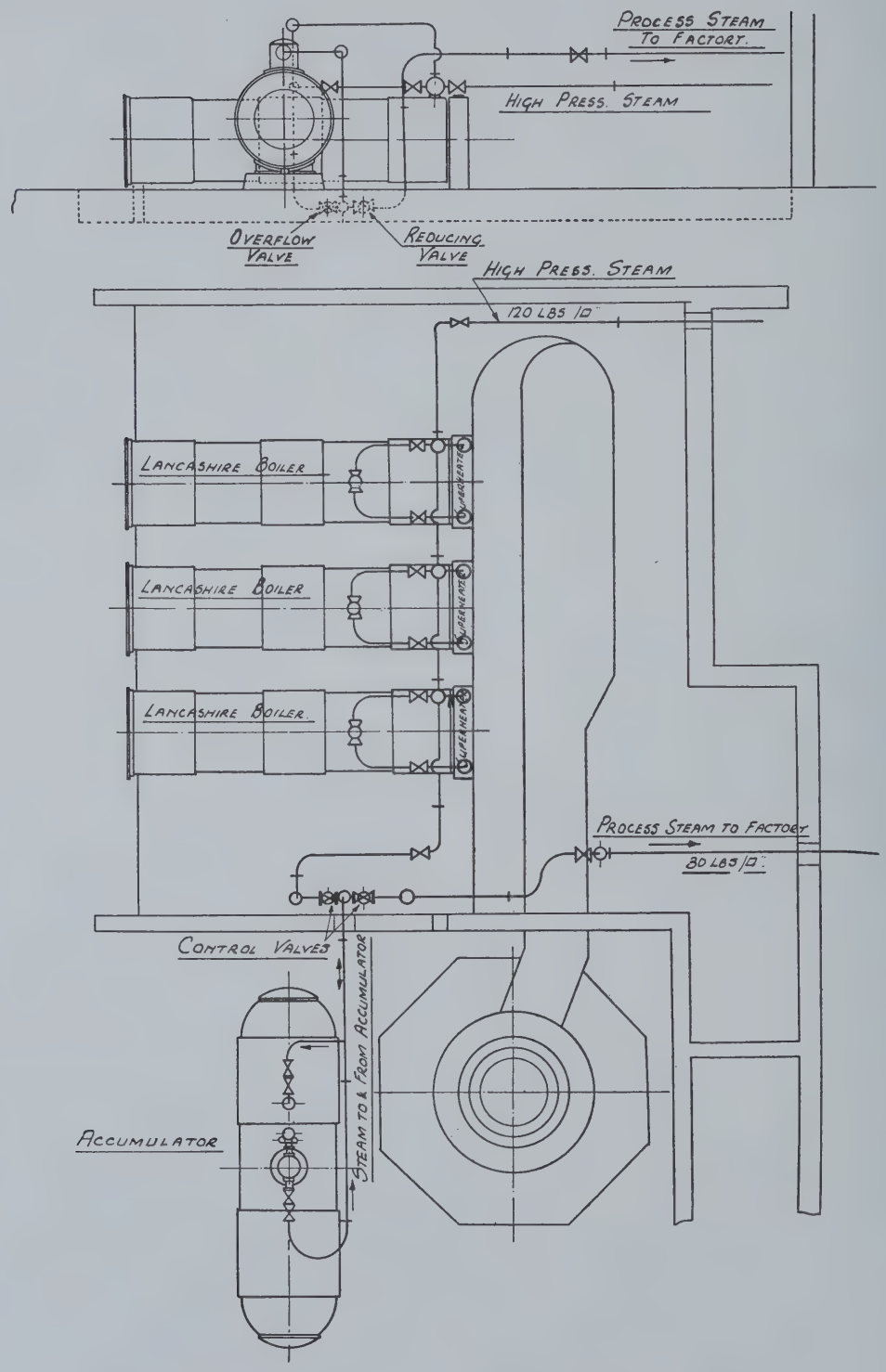


FIG. 4.—*Lay-out of Steam Plant Accumulator at Scottish Dye Works.*

accumulator. On the other hand when the steam demand in low-pressure line P exceeds the supply of steam to valve V_1—that is from the boilers—the pressure in the accumulator line O will drop, valve E will close and valve I will open and steam from the accumulator delivered to the low-pressure line P until the balance is reached.

A great many variations of layout have been adopted, not only for process steam requirements, but also for combined power and heating schemes and for purely power. It must, however, be pointed out that as for other engineering plants no generalisation can be made and each works must be considered on its merits and a scheme worked out to suit the particular conditions ruling. A general scheme is shown in Fig. 4 for an accumulator coupled to Lancashire boilers, supplying steam to high-pressure users at 120 lbs. and low-pressure users at 30 lbs./sq. in. pressure.

Constant pressure steam accumulation.

This system depends on the difference of temperature between that of the feed water and the temperature of the water in the boiler at the pressure at which it is working, and is limited to that extent. On the other hand, long periods of low load can be handled and substantially the whole of the thermal value contained in the stored water becomes available as steam delivery proceeds, and consequently the storage vessel is considerably smaller than for a variable pressure accumulator. In installations which have been made the peaks handled vary from 15 to 40 per cent. over long periods.

When surplus steam is available, that is during light load periods, a store of hot water at boiler temperature is created and kept in a separate container but in intimate contact with the boilers. When the demand for steam exceeds the normal supply—the boilers will be on an average load—the hot water in store is used and the normal cold feed slowed up and may at times be entirely stopped and the boilers will generate steam from feed supplied at boiler temperature, the heating of which has been carried out during periods of light load.

To ascertain the increase in the steam productions which will be secured by incorporating a constant pressure accumulator to take charge of the fluctuations in the steam system, the following general formulae are sufficient: $\frac{\text{Total steam heat—normal feed water temp.}}{\text{Total steam heat—accumulator heat}}$ Expressed in percentage the increase is: $100\times\frac{\text{Accumulator heat—normal feed water temp.}}{\text{Total steam heat—accumulator heat}}$ If the reduction of the boiler output during low load periods is required to be X per cent., then the feed water quantity must be increased.

$$1+\frac{X}{100}\times\frac{\text{Temperature of evaporation}}{\text{Accumulator heat—feed water temp.}}$$

The above general formulae pre-supposes the availability of the stored heated water for steam-raising purposes and a small margin of say plus 0.5 degree Fahrenheit should be allowed and added to the feed water temperature. The diagram in Fig. 5 gives the increase in steam delivery for feed water, between 0 and 150 degrees centigrade and boiler pressures of 6 to 30 atmospheres gauge.

A system which is now widely used in order to effect steam accumulation at boiler pressure and equalise the load, irrespective of the ultimate destination of the steam, that is whether for low-pressure or high-pressure consumers, is that worked out by Dr. C. Kiesselbach. Fig. 6 shows his system diagrammatically.

The storage drum, made to withstand the boiler pressure, is connected to the boilers by means of an overflow pipe taken off at the normal water level in the boiler. An equalising pressure pipe is also connected to the drum and the water is kept in circulation at an unvarying rate by means of a pump, either steam or electrically driven. In the case of certain water-tube boilers, the water is passed into the bottom drum of the boilers and effects improved circulation within the boiler. A regulator, inserted in the live steam pipe leading to the feed pump, controls the speed of the feed pump, and if economisers are used an auxiliary regulator is installed in the live steam pipe supplying the steam-driven feed pump to prevent steam formation in the tubes during such periods when the boiler feed is stopped by the chief regulator. The plant is insulated to the usual specification as given on page 505.

Method of working.

The boilers are fired on the average demand and the firing line is kept constant. If the demand for steam is more than the momentary supply from the boilers, the regulator will slow up and, if necessary, stop the feed pump, and during duration of the peak only accumulator water, that is water at boiler temperature, is used. On the other hand if more steam is produced than consumed no blowing off through the safety valves will take place, but the regulator will set the feed pumps going to supply the feed water required, which, in turn, will absorb the heat generated in excess of immediate requirements and the water will overflow into the storage tank. The water level of the boilers will remain constant and the level in the storage tank will always be fluctuating, but instead of the pressure varying as in the case of the variable pressure accumulator it is kept constant by the equalising pipe from the boilers.

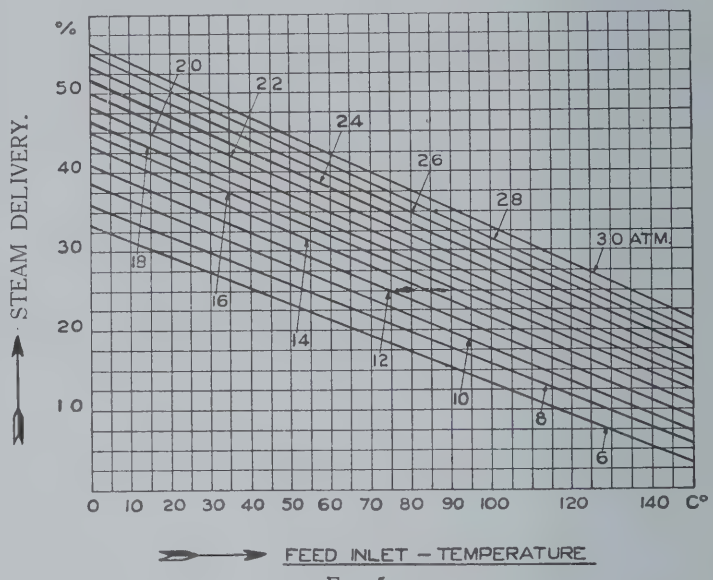


Fig. 5.

The constant pressure accumulator does not destroy the superheat as no steam goes to the consumers without passing the superheater if one is installed. An improved condition of the boiler drums

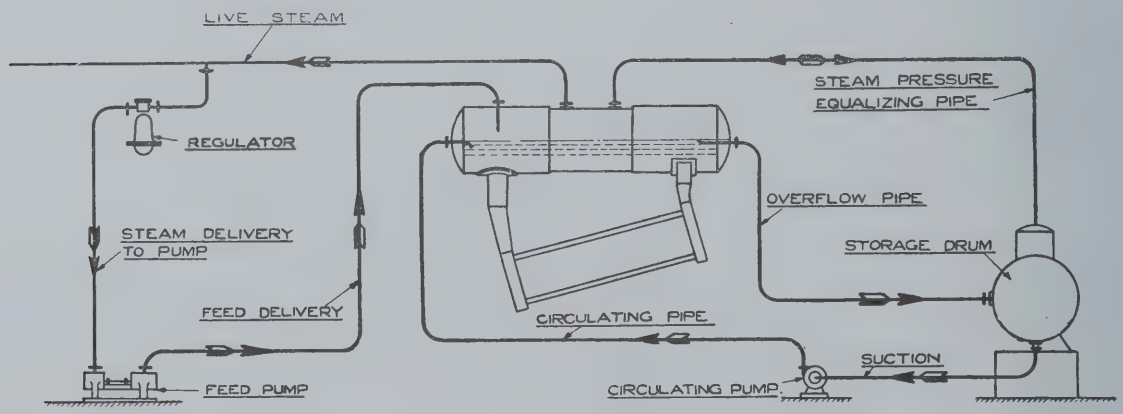


Fig. 6.

and tubes is effected owing to the water being kept on the move and, the mineral salts being unable to settle to the usual degree, settlement of the sludge takes place in the accumulator. As there is no fire under it no harm is done and occasional sludging should be provided for.

It may be thought that during prolonged periods when only accumulator water is being used for steam raising and very little feed water is flowing through the economisers if they are installed, the loss of heat in the flue gases will lower the general efficiency of the boiler plant. It is quite obvious that whilst the feed is slowed up or stopped, the temperature in the economiser will rise. Numerous tests have been carried out in this connection and the results show little or no loss in efficiency. The usual Green's economisers have a large water volume and consequently it was found that the rise in temperature proceeds very slowly, and steam formation in the economisers has not been known to happen. Should this danger be feared, then a small quantity of water is allowed to flow through. The equalising effect of the

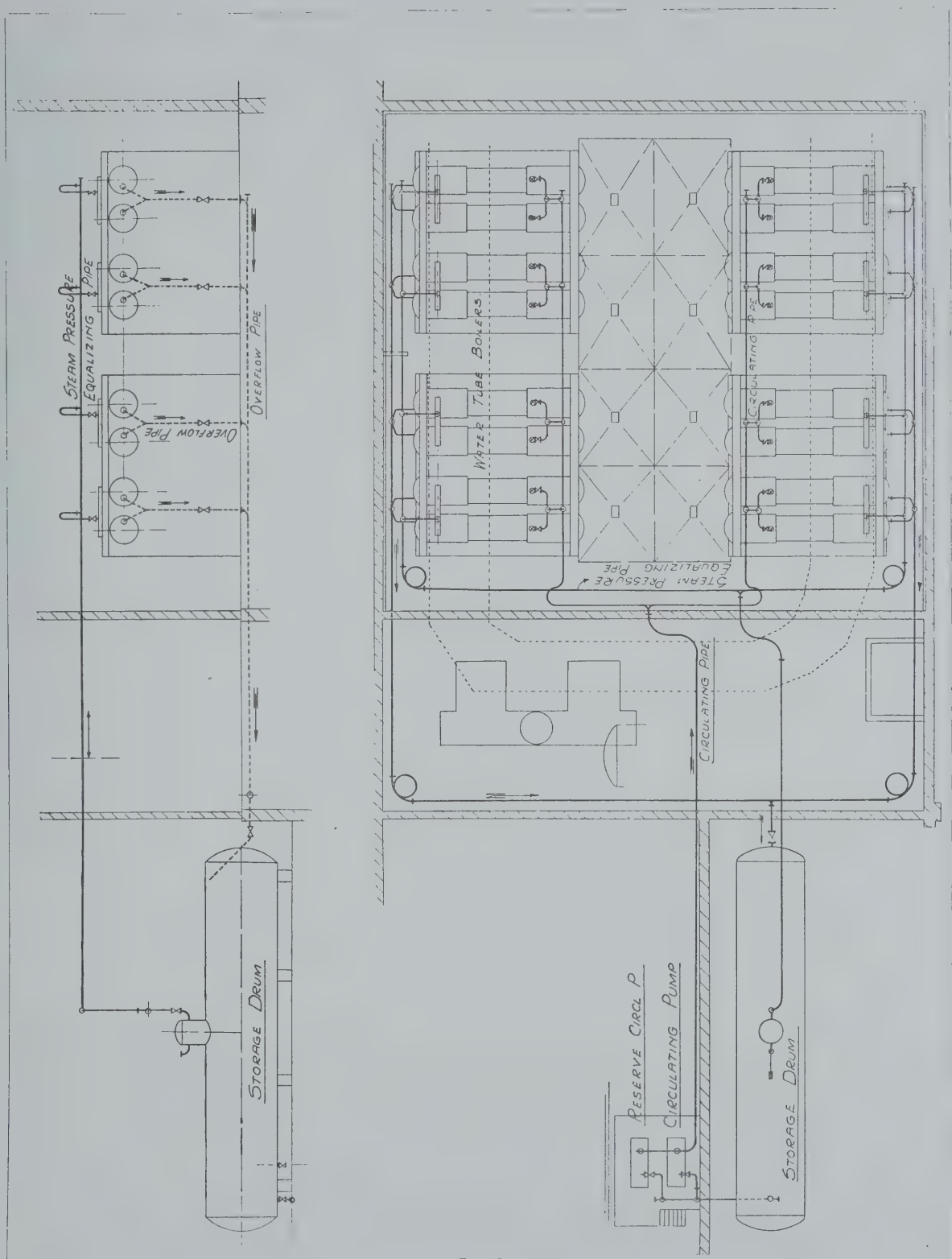

STEAM PRESSURE PIPE
EQUALIZING PIPE
OVERFLOW PIPE
OVERFLOW PIPE
WATER TUBE BOILERS
CIRCULATING PIPE
STEAM PRESSURE EQUALIZING PIPE
CIRCULATING PIPE
STORAGE DRUM
RESERVE CIRCL P
CIRCULATING PUMP
STORAGE DRUM

FIG. 7.

accumulator is substantially not diminished thereby as the water which is being pumped through the economiser enters the boilers at high pressure, although not quite steam temperature. In cases where an undue heating up of the economiser might be feared owing to prolonged peaks, the regulation of the water passing through would be controlled by a thermostat; so far this has not been found necessary. It is obvious that with a temperature rise in the economiser during prolonged peak periods above that obtained while working normally, the transmission of heat to the economiser is somewhat less, which, in effect, means during such periods a certain reduction in the heating effect, and vice versa, during periods of accelerated feed the economiser temperature becomes less, the temperature difference between the gases and the economisers is increased and the heat transmission becomes more favourable, that is to say, the heating effect is increased. The investigations clearly show that the two conditions substantially equalise one another.

Figure 7 shows a more detailed layout under this system to suit a battery of water-tube boilers at an electric power station supplying current for lighting and traction loads, with prolonged and difficult peaks at certain hours of the day.

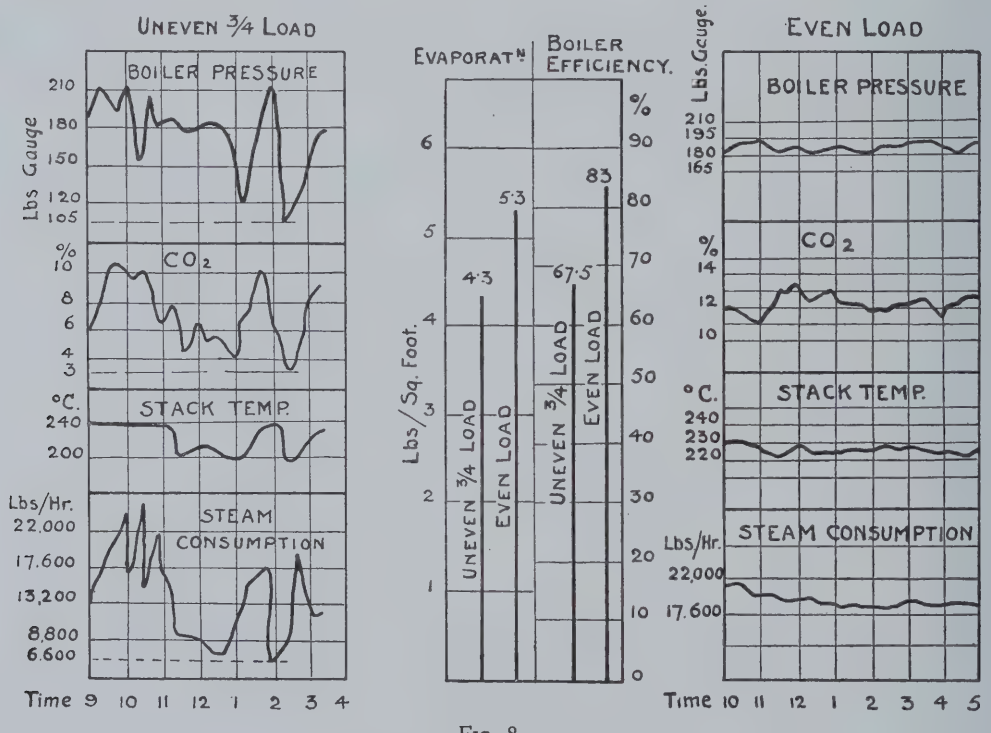


FIG. 8.

The industries in which steam accumulation plants are installed are now spread over a wide range and for both systems important economic results have been obtained. Owing to the reserve which is available, more care can be given to the firing conditions, and any alteration in the firing rate can be made without haste and with ample warning, and it is often found in practice that after the installation of an accumulator, the variations in the steam demand grow larger owing to the operatives being able to meet works conditions more easily and finding that their output is not retarded through lack of steam. General working costs in a works are considerably lowered and output of manufactured products is invariably increased; fuel saving is large and generally speaking the more intermittent the demand for and supply of steam the greater the saving; 10 to 25 per cent., according to the conditions ruling, is quite common. Some idea of the approximate amount to be expected when considering an installation for a particular works can be arrived at by ascertaining the boiler efficiency when the boilers are working under a steady load with regular firing and setting the figures against those obtained when the firing takes place under

factory conditions. This is a reasonably fair method, as the accumulator enables the boilers to be worked at an even firing rate and the pressures to be kept constant. Allowance, however, must be made for better starting-up and operating conditions when the accumulator is working and the economic reasons should it be desired to use a different type of fuel. The diagram shown in Fig. 8, published by Prof. Josse after a research on the effect of uneven loads on boiler efficiency, indicates the savings under the load conditions shown at the bottom of the left-hand diagram, but does not take into account the economies obtained by better steam consumption of the prime movers owing to constant pressure.

With wider knowledge of the advantages to be obtained by the adoption of steam accumulation in works where there are fluctuating loads and of the fact that it is not necessary to alter the general arrangement of the works to install a steam accumulator plant, a much greater application of the principle will result. Any type of boiler can be used and, generally speaking, wherever there is either or both a fluctuating demand and supply of steam, steam accumulation will effect economies and the costs of the plant cleared off in a short time. The application is, perhaps, more suitable to this country than to any other, and as the present systems have been developed along the lines of automatic control, the operation of steam accumulators in factories requires no great skill and does not mean the special training up of the staff.

Chapter 4.

UTILISATION OF WASTE HEAT AND EXHAUST FROM INTERNAL COMBUSTION ENGINES.

By Eng.-Commander W. P. Sillince, R.N. (Ret.), M.Inst.N.A.

This chapter is devoted to an analysis of the particular heat losses which are, at present, unavoidable in internal combustion engines, and it may be well to point out that the less efficient an engine is from the thermal point of view, the greater is the proportionate gain which results from recoveries obtained from its heat losses; therefore it cannot be expected that the same proportionate recoveries may be made from an efficient engine, as from one which is more wasteful. It is well to emphasize this point at the beginning, because it is frequently thought that a high percentage of recovery of heat from the waste of internal combustion engines indicates a highly efficient process in the aggregate, whereas it is not necessarily so at all.

The thermal efficiency of an engine is defined as the ratio of the heat equivalent of the useful work done to the heat contained in the fuel needed to perform this work. Given certain well-known thermodynamic conditions, a fundamental thermodynamic law is, that the higher the maximum and the lower the minimum temperature attained during the cycle, the greater is the maximum thermal efficiency. This is as true for any part of a cycle in which transfers or conversions of heat take place as for the whole cycle, and particularly applies to the processes of recovery of heat from waste or losses.

The thermal efficiency of an engine may be increased by improving the efficiency of its cycle of operations, i.e., by raising the standard of the cycle, and/or by increasing that proportion of the maximum theoretical efficiency which is actually realised with a given cycle. It does not necessarily follow, however, that an improvement in the cycle or in its maximum thermal efficiency will result in an improved overall performance and increase in the useful work done for a given expenditure of fuel. Generally, however, it may be said that improvement in the standard of the cycle does result in some proportionate improvement in overall efficiency. These notes do not propose to investigate the matter of improved thermal cycles, but the possibilities of improvement in overall efficiency by reducing losses and thereby increasing the output of useful work per unit of fuel expended.

It follows from what has just been said as to thermodynamic laws, that if heat which would otherwise be wasted is to be recovered, it is a more efficient process to recover and utilise heat units at a high than at a low temperature.

In steam installations, the working medium (steam) changes its state from a vapour to a liquid during the cycle, whilst in internal combustion engines the working medium (air) does not change its state; i.e., the exhaust from steam machinery is condensed, whilst in internal combustion engines it is not condensed or, at most, only a small percentage is condensed. Change in the state of the working medium involves changes in its heat contents without there necessarily being any corresponding variation in temperature or of pressure.

In the case of internal combustion machinery the thermal efficiency is greatly improved, as compared with steam plants, mainly in consequence of combustion taking place within instead of outside the working cylinder, and due also to the fact that no change in the state of the working medium occurs during the cycle. Heat is generated by the combustion of the fuel in the air, which forms the working medium, and a large increase in pressure, and sometimes in volume also, occurs during combustion.

Principal losses of heat.

Unburnt Fuel. In well-designed internal combustion engines there is present in the cylinder during each cycle an amount of air largely in excess of that necessary for the complete combustion of the charge of fuel and, at least for heavy-oil engines, the power rating is such that at the normal or full load there is practically no unburnt fuel discharged into the exhaust, either as hydrocarbons or as carbon monoxide.

Consequently, in such engines maintained in efficient condition, loss of heat due to unburnt fuel is practically negligible.

Jacketing. In order to control within safe limits the temperature of those working surfaces which are exposed to the heat of combustion, to facilitate efficient lubrication, and to avoid accumulations of heat, it is found necessary to jacket them with a cooling medium and to maintain a continuous circulation, usually of water, through the jacket spaces. It may here be noted that the late Dr. Diesel, in his original patent specification, provided amongst other things for a ratio of expansion so great that, although the maximum temperature and pressure was high and the terminal temperature and pressure very low (i.e., atmospheric), the mean temperature was such that water-jacketing was unnecessary, and, in fact, he proposed to lag the cylinders with insulating material to reduce radiation losses. This was, however, soon abandoned, as it involved cylinder proportions technically and commercially unsound, since the high maximum and low mean pressures involved a prohibitively heavy, bulky and expensive engine per unit of power.

Part of the heat of combustion, therefore, in a jacketed cylinder, passes through the cylinder walls and covers into the jacket water, performing no useful work; and this forms one of the main losses of heat in internal combustion engines.

Exhaust. As it is not found possible in practice to carry the expansion of the products of combustion down to atmospheric temperature and pressure, the products of combustion leave the cylinder at high temperature (600° to 1,250° F.) and at a pressure appreciably greater than atmospheric (25 to 40 lbs. per sq. inch). The heat so carried away is lost, so far as generating power in the engine is concerned, and constitutes a second, and the largest, loss of heat in internal combustion engines.

Total Heat Loss. The actual amount of heat lost to the jacket and to the exhaust, and their total, expressed as a percentage of the heat contained in the fuel used, depends upon the type of engine, its cycle, size and speed. It will be obvious, however, that an uneconomical engine with a low thermal efficiency rejects to the jackets and exhaust together a greater number of thermal units per unit of power than does a more economical engine. The results already achieved from waste-heat recovery, even in very economical engines, have been so satisfactory as to justify in all cases close investigation to this matter.

Typical Diesel engine heat balance.

The diagrams show graphically the heat balance of a typical good four-cycle Diesel oil engine, details of which are tabulated below:—

TABLE I.—TYPICAL FOUR-CYCLE DIESEL ENGINE HEAT BALANCE.

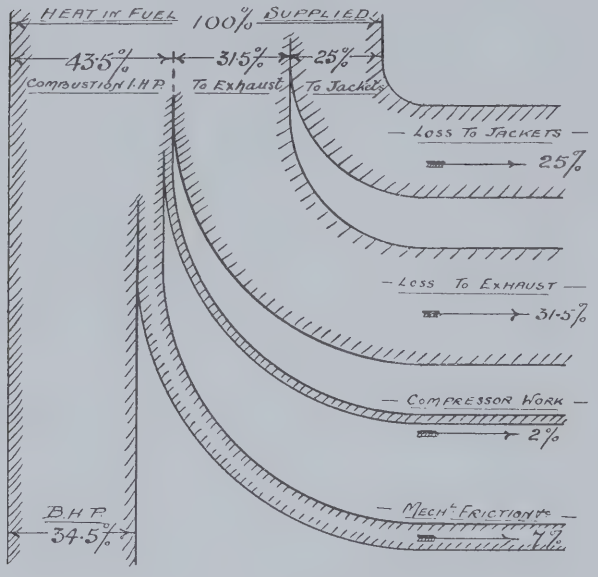
Heat Equivalents per B.H.P.	B.Th.U.'s.	Per cent.
Of useful work done (I.B.H.P.)	2,545	34.5
Of loss in mechanical friction, etc.	500	7
Of work in operating compressor...	150	2
Of loss by exhaust and radiation	2,325	31.5
Of loss to jacket cooling water	1,880	25
Total heat contained in fuel used per B.H.P.	7,400	100

The results of Table I. are also approximately obtained in the best of two-cycle Diesel engines; the loss to the exhaust is slightly more (about 3 to 5 per cent.), and that to the jacket rather less. For all practical purposes, however, the table may be taken to represent good practice in either the four-cycle or the two-cycle type.

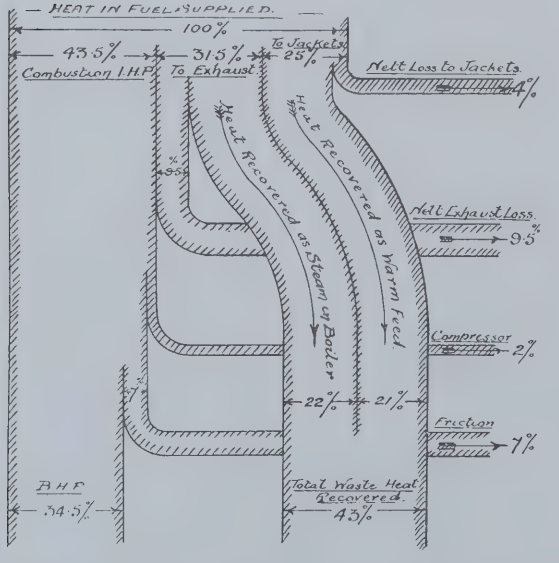
Loss to Jacket Water. The surfaces exposed to the heat of combustion, such as the cylinder liner and cover, and the piston crown, must be made of sufficient thickness and strength to withstand the maximum combustion pressure. Normally, in Diesel engines having air injection, this maximum is but

slightly in excess of the maximum compression pressure of 450 to 500 lbs. per sq. inch, but in direct or airless injection engines it may rise to 600 or 700 lbs. per sq. inch. This latter is due to the fact that, in airless injection engines, the rate of injection of fuel is such that combustion takes place partly at constant volume, and partly at constant pressure, the former portion of this "dual combustion cycle" being, of course, responsible for the rise in pressure. Incidentally, it adds to the economy, since the maximum temperature of the cycle is increased and is highest at the dead centre instead of at some point further along the stroke as with constant-pressure combustion.

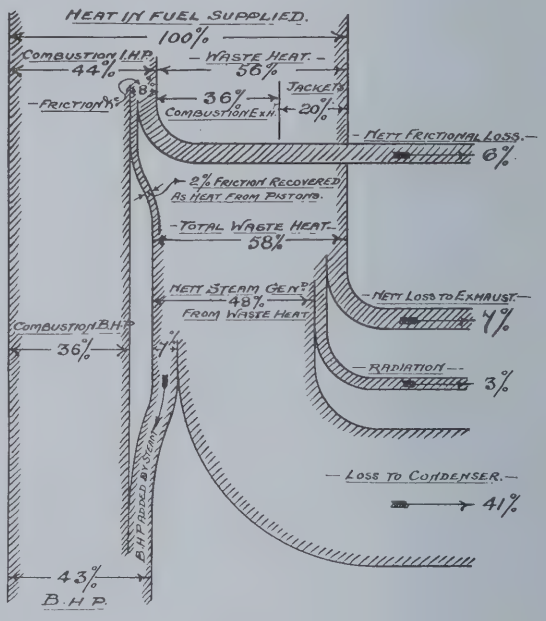
Owing to certain contingencies which may accidentally arise in certain designs (such as stuck or leaky fuel valves, pre-igitions after misfiring, or super-compression effects due to leaky or sluggish air starting valves), it is necessary to provide a large margin of strength; in fact, sufficient to prevent over-stressing should a full charge be ignited at constant volume instead of at constant pressure, whereby a pressure about 3½ times as great as the normal is created. Hence, for a cylinder of given bore and with material of known mechanical and physical properties, the thickness of cylinder walls, cylinder covers and piston crowns are fixed as a minimum, in normal designs, by considerations of strength under internal pressure.



Typical Heat Balance Diagram for four-stroke cycle Diesel Engine (without Waste Heat Recovery).



Typical Heat Balance Diagram for Four-stroke Cycle Diesel Oil Engine, with Waste Heat Recovery, from Jackets as Feed and from Exhaust as Steam.



Typical Heat Balance Diagram for Diesel Engine with Heat Recovery.

NOTE.—A brake thermal efficiency of 43 per cent. is equivalent (with fuel of 8,500 B.Th.U.'s per lb.) to 0.32 lb. per B.H.P. per hour.

Further, in order to enable the heat to be transmitted through these thick surfaces at a sufficiently rapid mean rate per unit area of surface, three conditions are necessary:—(1) A definite difference in tem-

perature must exist between the combustion products at the completion of combustion and the interior surface of walls exposed to these products; (2) a definite temperature difference must exist between the two sides of the metal of the walls; (3) a definite difference in temperature must exist between the metal at the outer surface of the wall and the jacket water in contact with it. It should here be noted that for a given rate of heat flow the temperature difference in the metal is proportional to the thickness of the metal. Stresses due to temperature are proportional to the difference of temperature and, therefore, for a given rate of heat flow to the thickness.

During normal working of the engine all these four temperatures, and therefore their differences, adjust themselves until, when a steady state is reached, the heat carried away by the jacket water is equal to the heat received by the walls. Scale on the jacket surfaces and stagnant pockets or air locks in the jacket system have the effect of very rapidly increasing the maximum and the mean temperature of the metal for a given rate of heat transmission, resulting in destruction of the effective lubrication of liners and pistons, accompanied by rapid wear, distortion, cracking and possible seizure of these vital parts.

Quite apart from the probability of the jacket water containing salts in solution which precipitate at a temperature below 212° F., it is found in practice, with normal designs, that the outlet temperature of water from the jacket system must not exceed about 130° F. as a maximum; more usually 110°-120° F. is regarded as sufficiently high. The quantity of water circulated under these conditions depends upon the inlet jacket temperature, and is designed or regulated so as to control the outlet temperature to the maximum above-mentioned.

It will thus be seen that although the temperature of the products of combustion at the completion of the ignition or combustion period may be so high as 3,000° to 3,500° F., and that the inner surface of the top of the liner may be 300° to 400° F., the temperature of the jacket water after receiving the heat rejected to it is no greater than 130° F. If, for the moment, we consider the jackets as receiving heat for the sole purpose of enabling this heat to be subsequently recovered, it will be seen that the process is very inefficient, since the maximum temperature at which the heat is generated by combustion (3,000°-3,500° F.) has been frittered down by temperature drops and gradients, until the maximum temperature available in the jacket water for heat recovery is 130° F., although the quantity of heat available for recovery is about 25 per cent. of the heat of combustion. Were it possible to considerably increase the jacket water temperature, recovery of heat from it would be facilitated and made much more efficient.

Thus, in ordinary practice hitherto, the heat available for recovery from the jacket water has not been capable of utilisation for purpose of increasing the useful work done by the engine for a given expenditure of fuel, and the only useful purposes to which jacket heat has been applied, so far as the writer is aware, have been extraneous to the engine itself, such as for circulating through heating pipes for warming buildings, as a supply of warm feed to independent steam plants, for domestic and surgical use, for preheating fuel, and for certain process work, such as dyeing.

So far as ordinary types of internal combustion engines are concerned, it may be said that the loss to jackets is not capable of material reduction, nor is heat recovery for purposes of power augmentation in the engine itself possible, although the recovery of heat from the jacket water for purposes external to the engine itself is none the less desirable and economical.

Loss to the Exhaust. For reasons already pointed out, the products of combustion are released from the cylinder at high temperature (600° to 1,250° F. at full load in normal engines), and at a pressure of from 25 to 40 lbs. per sq. inch above the atmosphere. The pressure loss is not a very serious matter, since, in any case, the products of combustion must be discharged into the atmosphere and are not condensed as in steam. Also, a certain pressure difference is required to give the exhaust gases the high velocity necessary to quickly evacuate the bulk of them from the cylinder and so avoid back pressure and negative work. Frequently, too, the momentum of the exhaust gases is utilised to assist in the charging of the cylinder with air for the succeeding cycle, and so reduces pumping losses.

The serious portion of the loss is that due to temperature, and with no attempt at heat recovery over 30 per cent. of the heat of combustion of the fuel may escape to waste. Also, this is valuable heat, at high temperature, and not the low-temperature heat of the jacket system. Great success has already attended the recovery of heat from exhaust gases.

Exhaust-heat boilers.

Several successful exhaust-heat boilers, usually of tubular type, having efficiencies of from 50 to 75 per cent., are on the market, generating steam under pressures up to 180 lbs. per sq. inch from the exhaust gases of internal combustion engines. By means of these boilers from 1 to $3\frac{1}{2}$ lbs. of steam may be generated per hour per B.H.P. of the engine at full load, the amount depending upon the thermal efficiency and condition of the engine and the percentage of its heat of combustion rejected to the exhaust.

It is essential, if the process of exhaust heat recovery is to be efficient, that the exhaust gases be led into the boiler with as little loss of radiant heat and of temperature as possible. This means that the boiler must be placed in the closest possible proximity to the engine. This important point is often overlooked. In some cases loss of efficiency in exhaust-heat recovery must be accepted, owing to conditions on site which prevent the boiler from being placed close to the engine. Exhaust gases rapidly lose their temperature by radiation when passing at high speed through even short lengths of exposed piping. One case is recorded where the radiation from a 20-ft. length of 8-in. bore piping caused the gas to fall from 668° F. to 480° F., i.e., by 188°, or 28 per cent. Of course, the radiation from the first foot greatly exceeds that from the second, and so on. Another recorded case showed that a temperature drop of 28 per cent. occurred in a 27-ft. lagged length of 12-in. exhaust pipe.

Exhaust-heat boilers need cause no appreciable additional back pressure on the engine, provided sufficient area of flow for the gases is provided, particularly at the inlet end, and if abnormally high gas speeds and abrupt changes of direction are avoided. Moreover, as the gases are cooled by the abstraction of heat, their volume diminishes, thus gradually reducing the speed (if the area of flow is kept constant) as the temperature gradually falls. This gradual reduction of speed, quite apart from the damping effect of tubes upon exhaust pulsations, assists greatly in quietening the final exhaust.

This gradual reduction of speed also means that higher gas speeds may be used at the high-temperature end of the boiler tubes (in a tubular boiler), giving thereby a higher and more rapid heat extraction per unit length of tube, the gas speeds becoming less and less as the temperature falls and being less than normal at outlet; the mean gas velocity thus providing an automatic compensation against excessive frictional and back pressure losses due to gas speed through tubes.

If the fuel contains any appreciable quantity of sulphur, the exhaust will contain sulphurous oxides, which, in the presence of moisture, form sulphuric acid which causes rapid corrosion of wrought iron and steel, although cast-iron is fairly immune. In using such gases, it is necessary that their temperature be not reduced by heat extraction within the boiler tubes, etc., below that at which moisture may be precipitated. Continuous drainage is also important for the same reasons. In practice, such boilers are usually proportioned so that the gases leave them at about 400° F., this being about 70° F. to 40° F. above the saturation temperature of steam at the pressures generally adopted in such boilers, viz., 80 to 150 lbs. per sq. inch. Any further heat extraction required is then carried out in a separate and easily-renewable feed-water heater or economiser, constructed preferably in cast-iron, and in which the gases may be cooled to, say, 150° F., or even lower. Certain electricity-generating stations using mixed internal combustion engines and steam plant apply the exhaust from the former to heat the feed water for the latter. This makes a simple and inexpensive arrangement.

A greater proportion of the waste heat can be recovered in the form of hot water than in steam, since the temperature of the gases leaving the steam-raising boiler, obviously, must be higher than the boiler temperature. In the case of a boiler generating steam at, say, 100 lbs. per sq. in., the final temperature of the exhaust gases would approach 400° F., which does not show a great recovery from the engine exhaust temperature of an efficiently-operating engine. If, on the other hand, the waste heat is used for water heating, with temperatures up to, say, 200° F., more than double the amount of heat can be extracted from the gases. An example of this application is seen in the Diesel generating plant at King's College Hospital, where the exhaust from two 150 B.H.P. and one 75 B.H.P. engines is passed through an air heater supplying air to three Lancashire boilers installed for heating, cooking and hot-water services. The air is preheated, and the resultant saving on the fuel bill is about 2 per cent., or over £100 per annum. The cooling water from the Diesel cylinder jackets, also, is utilised for supplying the hospital's hot-water system.

Chapter 5.

MEASURING INSTRUMENTS FOR FUEL AND ENERGY CONTROL.

By F. J. Bailey, M.Sc.

A considerable number of the fuel problems have been and can be solved only by means of systems of "scientific accountancy." Regular returns of fuel consumptions, rates of production, temperatures and pressures, etc., are necessary, and these can be obtained only by adequate and careful use of scientific systems of measurement and recording.

Thus, the fuel problems discussed, are intimately bound up with the parallel problems of measurement, and although the latter are virtually minor ones, any specific fuel problem, can, generally speaking, only be completely solved after the solution of all the measurement questions involved.

Moreover, in order that the economies to be effected shall be valid, it is essential that any measurements made in connection with them shall be as accurate as possible for the lowest possible outlay in money, time and effort. In many cases, the extra accuracy to be obtained by means of a larger capital outlay on the instruments is not justified, whereas, on the other hand, it is often well worth while to pay out the larger capital necessary in order to obtain this increase in accuracy and reliability of the figures.

It will readily be observed that, in order to obtain the best return for capital, time and energy expended, it is of the utmost importance to have a complete survey of the whole field of measurement, both from the point of view of what can, and has been done, and also what may be done in the future.

Thanks to the brilliant scientific work of our own physicists, chemists and technical men, as well as to that done by the Americans, the Germans, and the French, the theory of measurement and the development of measuring instruments, has been placed far ahead of the practical application in the industrial world for uses other than those which may be included in the wide term of research. In the days of cheap fuel in this country, the market for industrial instruments in connection with problems of fuel economy was, of course, very small, so that the development of good, cheap, reliable instruments has, to some large extent, been left to our competitors, to whom it was a necessity to face and solve the problems of fuel economy, in order that they might place their goods on the market at competitive prices. The chemical industries, however, in their rapid development, and their efforts at reducing general production costs, created a larger market, which is now being further expanded by the more general national efforts towards economy, by reason of high fuel costs. The British makers have successfully laid themselves out to develop along lines which would meet these demands, and although they have not, perhaps, attained the technical efficiency of their continental competitors, they are, thanks to the experience already gained, rapidly doing so.

Research instruments.

Measuring instruments for research have been highly developed, but these are designed essentially to work under controlled conditions in the hands of highly-skilled operators who can maintain a constant watch over them. On the other hand, industrial instruments may be, and are, subjected over long periods to the attentions of semi-skilled operators, and must be capable of withstanding ordinary works' conditions of dirt, shock and vibration. The qualities that are requisite and desirable for works' instruments are set out in the following paragraphs :—

(1) *Ease of Application to Existing Plant.* Where extensive alterations in design of the plant are necessary in order to install instruments, the cost of making these alterations, must be debited to the cost of measurement, and may thus become a more important charge than the prime cost of the instruments. Also, it is equally important that the instrument should not interfere with the normal operation of the plant.

(2) *Low Running Cost.* Similarly, the instrument must not make big demands on the power inherent in the material being measured, or on external power for actuating any mechanism, while, at the same time, the consumption of water, gas, chemicals, etc., should be as low as possible.

(3) *Simplicity of Operation.* The mechanical moving parts should be as few as possible and free from excessive friction and the possibilities of sticking. At the same time they should be as accessible as is possible in order to facilitate cleaning and renewals, etc.

(4) *Ease of Checking.* It should be a simple, straightforward operation to check the zero reading or/and wherever possible to check the accuracy of a mid-scale reading.

(5) *Simple Adjustment.* Adjustments for maintaining the accuracy of the readings should be as few and as simple as possible. Where semi-continuous adjustment is necessary it should be automatic if possible.

(6) *Robustness.* Without being heavy or clumsy the construction should be solid and the instrument as a whole a "good engineering job," particularly the design should be such as to withstand possible damage by ordinary works' usage, *i.e.*, weather, shocks, vibration, fumes, grit, etc.

(7) *Atmospheric Conditions.* The applications to indicating or metering should be independent o f changes of atmospheric temperature and pressure, although the former variation is of less importance where the instrument is to be specially housed, *e.g.*, in a central control room.

(8) *Direct Reading.* Since the routine reading and the control of the instrument is usually in the hands of semi-skilled, or unskilled, operators, the corrected readings in the units desired should be easily and directly read.

(9) *Recording and Totalising.* For most phases of plant control a total figure integrated against time is essential. An indicator showing the instantaneous rate of flow, temperature, etc., and, at the same time, giving records is often extremely valuable also.

(10) *Transmission to a Distance.* In order to facilitate the centralisation of controls it is of distinct advantage to have duplicate, or the whole indicating, recording and totalising gear at any given distance from the point of measurement.

Plant control.

In the foregoing discussion of the qualities that are desirable where works' instruments are concerned, indicators, recorders, and totalisers have all been considered as parts of each individual instrument, but it should be pointed out that their uses belong to different aspects of the problem, and the relative utility of indicators, recorders and totalisers involves the deeper problem of the methods of plant control to be employed. For this purpose plant control may be considered as being divided into three distinct phases, namely:—(a) The instantaneous control of the plant operation by the workmen and/or foreman in charge. It is, of course, obvious that this necessitates simple and direct reading indicators for cases where the flow or temperatures, etc., is to be kept within definite limits. Wherever a time factor is to be introduced into this control it is of considerable importance that a recorder giving a permanent visible record should either be included with the indicator or should work in conjunction with it. (b) The control by the departmental manager of the operation of the plant by workmen and/or foreman. In order that this control shall be effective and simple a permanent and easily-read record is indispensable. (c) Statistical and general control by the manager and/or fuel officers. For this purpose, not only are permanent records required, but also the weekly or monthly totals of consumption, throughput, and production are required, and, in consequence, the instrument must be capable of supplying totalised figures, or, at least, figures which are easy to totalise by means of simple arithmetical methods.

From this it would, at first sight, appear that the ideal instrument would always be that which combined these requirements, but this is not necessarily the case. Actually in practice, a multiplicity of recording instruments may become a nuisance to the people responsible, and be treated accordingly, while, at the same time, a large number of different gauges are apt to become extremely confusing to the men on the job. Moreover, it is only occasionally that the information which is most useful as a recorded total, is also the most useful instantaneous indication of the running conditions on the work. Thus, it is very often the case that the instruments required shall be either indicators, recorders or totalisers, without any combination of properties. For example, let us take the well-known case of boiler-house control, where it is of advantage to the fireman to have an indication of, say, his boiler pressure and boiler load, and a record

of his percentage of carbon dioxide and draught. On the other hand, the management or fuel officer may require in addition, weekly totalised returns of fuel consumption and steam output.

Supervision essential.

All manufacturers of industrial instruments attempt to market articles which can be placed in the hands of at least semi-skilled operators, requiring the minimum of attention, but it cannot be too strongly emphasised that no instrument can be expected to give good results continuously, without at least occasional intelligent overhauling by a man who understands the fundamentals of measurement. Further, all instruments may be reasonably expected to give better and more regular results when in the hands of a skilled operator, so that wherever instruments are installed they should at least be under the supervision, if not receiving the regular attention, of the fuel officer, or some other such person, who is completely responsible for their smooth running. This will be rapidly made evident by anyone who cares to examine and compare with a standard the whole of the pressure gauges in any one works, where this is not done. Even the boiler gauges, which are essential to safety, are liable to be inaccurate, and it is almost safe to say that all others are fairly sure to be so. Thus, a capable man definitely made responsible for the whole of the instruments installed is a good investment in any case, and almost essential where large numbers of instruments are concerned, for, not only do the results obtained become more reliable, but the same class of results may be obtained with a relatively cheaper type of instrument.

A detailed survey of all the instruments now on the market could not be brought within the limits of a single chapter, and, in any case, many of the details of design described might be quickly superseded, but it is interesting and instructive to glance, briefly, at the major developments which have recently taken place, and the more outstanding problems still being handled by the pioneers.

Solid material measurement.

The measurement of quantities of solid materials has been carried out on a large scale with considerable accuracy for a long time, and it will suffice to consider only the more modern developments. Weighing machines of the platform type may now be obtained which supply a printed record of the weight measured, which is protected from "adjustment" by the operator, while an instantaneous dial indication may be obtained by balancing against the submergence of a float into mercury through a system of levers. Small materials which can be fed in a stream into a hopper can be automatically weighed by causing the hopper, when loaded to a given weight, to cut off the stream, empty itself and re-start the cycle.

Where solids are being handled by conveyors it is possible, by automatically balancing a given section of the conveyor, to obtain an integrated total of weight which has passed over. Similarly, if the materials are fed through a trough of constant standard width and the top surface is levelled by a heavy "float" which, at the same time, gives a constant indication of the depth of solids passing, a record may be obtained of the total apparent volume which has passed. In the case of coals where the nett weight of each class of coal of constant moisture content has constant volume we may thus obtain reasonably accurate measurement of the weight of coal which has passed.

By applying the weight to be measured to a hydraulic ram or cell and obtaining an indication of the pressure set up by means of a pressure gauge, a simple instrument is obtained which occupies small space and is adaptable to inclusion in a crane sling.

Third measurement.

In the measurement of fluids a Pitot tube will indicate the velocity at any point in a fluid stream, since a reading is obtained which is a measure of the momentum. Such a reading at the point of average velocity in a pipe or duct of known area gives a measure of the total flow. When the velocity is low the pressure head equivalent to the momentum becomes extremely difficult to measure and record accurately, and the method ceases to be of use.

Where the flow is restricted the fall in pressure head due to the change in the momentum of the fluid stream is again proportional to the square of the velocity, but in this case the average figure for the whole gas stream is given directly. It is possible to use any convenient restriction or resistance provided it is calibrated, but it is normally simplest to insert a " sharp-edged orifice plate," while for economy in loss of pressure head a venturi restriction is used. Although this system is widely applicable considerable difficulties are encountered with low rates of flow, such as are normally designed for in low-pressure gas ducts, with high viscosity liquids, with hot dirty gases which change considerably in density on account of the changes in solid and liquid content and in temperature, and which tend to " make up " both the ducts and the orifices. Further difficulties are encountered with rapidly pulsating flows since, owing to the inertia of the measuring medium, no record can show a true mean of the velocity which varies as the square root of pressure loss.

This difficulty has been obviated by by-passing a definite proportion of the total volume of fluid through a small low-resistance damped turbine, which drives an external counting mechanism by means of a magnetic coupling. This standard device may be applied to any sized pipe-line, and used in conjunction with a recording differential manometer, allows of a complete and accurate history of the fluid flow being made.

Temperature measurement.

The construction and uses of mercury-in-steel and other dial thermometers, resistance thermometers, thermo couple pyrometers, radiation and optical pyrometers are too well known to require more than passing mention here. Where delicate temperature control is being undertaken, it must be remembered, however, that in exposed positions the atmospheric temperature variations exert a considerable effect in many cases, and that this can be, and should be, automatically corrected.

Gas analyses.

In the field of automatic gas analysis great strides have been made with instruments dependent on physical properties such as heat conductivity, density, viscosity, etc., but the problem of long continued stability under adverse conditions is still a difficult one. An extremely useful development is that of an all-metal mechanically-driven absorption instrument, which is a good engineering job requiring less wattage than the average electric lamp, and capable of several months' reliable running with the least possible attention under adverse conditions.

Although it has been possible to produce combined records of carbon dioxide, carbon monoxide and hydrogen in producer and blast furnace gas, the production of records of the carbon dioxide and the monoxide independently of the other combustibles still remains to be satisfactorily solved.

In brief, it may be said that although our greater problems lie in the proper and more widespread use of instruments, there still remain many interesting problems in the improvement of existing instruments, and the development of others or more efficient types to deal with practical question as yet unsolved.

PART IX.—REFRACTORY MATERIALS.

Chapter 1.

BRITISH RESOURCES OF REFRACTORY MATERIALS.

By H. P. Lewis, M.A., F.G.S.

Great Britain is fortunate in possessing large resources of materials which are necessary for the construction and maintenance of all types of furnaces.

The rocks, from which these supplies are obtainable, were deposited, with few exceptions, during the Carboniferous Period and, usually, belong to the Coal Measure and Millstone Grit Series. This applies, in particular, to the fireclays, which are the most important of the raw materials. The silica-rocks, sands and dolomite come from more varied sources, but even they are found largely within, or in association with, Carboniferous rocks.

During 1925 the British output of fireclay was two and a quarter million tons, and in the same year the production of silica-refractory materials was half a million tons.

CLAY DEPOSITS.

The chief supply of clay used in the manufacture of refractory goods is derived from the fireclays. Other clays, such as the plastic ball-clays and china-clay, are used to a much less extent.

Any heat-resisting clay can obviously be deemed a "fireclay," but this designation is, usually, retained for certain clays which have been deposited in measures which contain coals, such as the Carboniferous measures and those of the Jurassic Estuarine Series.

Fireclay often forms the whole or part of the underclay, or seat-earth, of a coal seam. Owing, however, to the littoral conditions which operated during the accumulation of coal-bearing strata, the whole of the overlying coal may have been removed by local erosion, prior to the deposition of later rocks. It sometimes happens, also, that an underclay extends over a wider area than the coal which in places accompanies it, while some fireclays show no evidence of association with a coal.

A seat-earth often varies, considerably, in chemical composition and in texture. Thus, a passage may sometimes be observed from an aluminous fireclay to a ganister rock. Some fireclays are aluminous, others siliceous, and the best types contain little iron-oxide, lime, magnesia, alkalies, or other fluxing matter.

Fireclay material is often referred to in the terminology of miners, borers and sinkers as "seggar," "spavin," "warrant" and "clunch." The more serviceable fireclays are, usually, soapy, non-laminated and more or less plastic. They are dark or light grey in colour, and often break along curved fracture-planes.

A detailed classification of the fireclays is difficult, owing to the fact that, in addition to refractoriness, other variable factors, such as texture, plasticity, tensile strength, and rate of contraction on drying and firing, are of great importance for certain purposes. Very few fireclays combine all the desirable physical and chemical properties, so that clays which are refractory, are often blended with others which are more plastic, or in other ways superior. Moreover, plasticity and reduction in the alkali and iron content are, sometimes, induced by weathering the clays for long periods. It is, thus, difficult to draw distinction between the fireclays. Out of the great mass of clay of moderate quality, some portions of a seam are found to serve one purpose, and some to serve another.

Carboniferous Limestone Series. Two fireclays, one near Haltwhistle, the other near Corbridge, have been worked from this series in N.E. England. In Scotland, the Ferguslie and other fireclay seams, belonging to the Calciferous Sandstone Series, are worked in the Paisley district, while two others occur in the Carboniferous Limestone Series east of Barrhead.

Millstone Grit Series. The best known Scottish refractory clays are all derived from these measures, but, in England, they have only been exploited for fireclay, in one or two instances, in the Pennine region.

In Scotland, the main supplies come from the western side of the Central Coalfield, between Glasgow and Bonnybridge; Bonnybridge, Castlecary, Glenboig and Garnkirk being the chief centres of the fireclay industry. Two clay groups occur and these are termed the Lower and Upper Fireclays.

The Lower Fireclay is rarely more than 60 feet above the base of the Grit Series. In part of the Glenboig area (Lanarkshire), it is made up of a lower "White," or "Main," clay and an upper dark clay, known as the "Blue," or "Twiggy" clay. These are, in places, separated by a sandstone up to 12 feet in thickness. The lower bed provides the most refractory clay, except at Gain, where the "Blue" clay is the better seam. The thickness of the clay worked, varies from about five to twelve feet. Lateral variation in the character of the clay, necessitates selection and blending.

Near Castlecary, the Main Seam is, usually, eight to nine feet thick and has a sandstone roof, as at Glenboig. Two refractory clays, nearer the base of the Grit Series, are also found at Castlecary. Clays at the Lower Fireclay horizon occur further north and also on the eastern side of the Central Coalfield, near and to the south of Linlithgow.

In North Ayrshire, a widely-distributed fireclay known as the Monkcastle Clay, occurs near the base of the Grits. Near Dalry, the seam is about ten feet thick.

The "Upper Fireclay" is the name given to certain fireclay and "ganister" seams, near the top of the Millstone Grit Series, in the Central Coalfield. In the Bonnybridge district of Stirlingshire, the group comprises two or three fireclays and one or two associated ganister beds, varying in collective thickness, from thirteen to twenty-two feet. The individual beds are variable in character and thickness. The clays are aluminous and refractory, although some of them are high in iron-oxide. Fireclays, at a similar horizon, have been worked near Armadale and Salsburgh.

Highly refractory material, usually very hard, with low plasticity, well-jointed, possessing a conchoidal fracture and known as the Ayrshire Bauxitic Clay, occurs in North Ayrshire. Similar bauxitic clays have been found in Arran, near Stranraer, in Wigtownshire, and in the Sanquhar Coalfield.

Lower Coal Measures. The fireclays worked in the East Pennine Coalfield are nearly all obtained from the lowest, or "Ganister Measures" of the Lower Coal Measures. The lowest refractory clay, occurring a few feet above the Millstone Grit, is the aluminous Black Pot-Clay, which is extensively worked on the west and north-west of Sheffield. The clay, usually, varies from two to five feet in thickness. Where well-weathered at outcrop, it is most plastic and refractory, but in from outcrop, carbonaceous and ferruginous matter may be present. The quality is variable. The best crucible-clay is, usually, dark grey and smooth, and possesses shining slip-faces.

Most of the fireclay in the Don Valley comes from below the Clay Coal and the Ganister, or Halifax Hard Bed Coal. The clay below the Ganister Coal attains a thickness of five feet, at Oughtibridge, and is extensively worked with the associated ganister. It is siliceous and variable in quality. Another siliceous clay with low alkali content, known as the White Car Clay, is obtained from below the Halifax Hard Bed Band Coal near Deepcar. Near Halifax, this clay is highly aluminous and, in places, is ten feet thick.

In the Elland and Halifax district, the 36-Yard Band Fireclay becomes important, and at Elland, is six to seven feet thick. The underclay of the Better Bed Coal has been worked, fairly extensively, in the neighbourhood of Lowmoor.

The Lower Coal Measures, also, provide the bulk of the refractory clays in the West Pennine Coalfield. Of these, the underclay of the Lower Mountain Mine is the most refractory in the coalfield. In this coalfield, the underclays of the Mountain Four Foot Coal, the Upper and Middle Mountain Mines and the Lower Foot Mine are also worked.

In the Cumberland Coalfield, the best Lower Coal Measure fireclay is that which underlies the 43-Yards, or Micklam Fireclay Coal. It is siliceous and, usually, fairly uniform. Other fireclays occur with it in the measures beneath the Six Quarters Coal and above the Four Foot Coal.

At the Tow Law ganister quarries (Durham) a fireclay which occurs near the base of the Coal Measures is worked.

In Denbighshire, several fireclays associated with coals, near the base of the Coal Measures, are worked at Trevor, Acrefair and Rhosllanerchrugog.

Middle and Upper Measures. In the Midlands, the Middle Coal Measures are the source of most of the refractory clay of good quality. The chief clay-producing area lies east of Stourbridge, in the South Staffordshire and North Worcestershire Coalfield. The principal fireclay seams worked, all occur within some 200 feet of measures, which are present, as a result of folding and faulting, within workable distance of the surface, in several localities.

The clays associated with the Brooch, Thick, Top Heathen, and Lower Heathen Coals are used, but the fame of the area as a producer of high-grade refractory clays is, mainly, due to the good qualities of the best Old Mine Clay. This occurs at its best in the vicinity of Amblecote, Brettell Lane, Hungary Hill, etc., where it varies from, about, four to seven feet in thickness. When followed to the south-east towards Cradley, it becomes thinner and is in places, overlain by the Sulphur Coal.

Variation in the alumina-silica ratio, occurs both vertically and laterally, necessitating careful selection. Typically, a division of the seam can be made into a top black mild clay, with an alumina content of 40 per cent. or so; a middle dark grey stronger clay, with alumina up to 28 per cent., and a bottom pale grey strong siliceous clay. These three grades are not always represented and their positions in the seam are variable, so that separation of the clay into "best," "seconds" and "offals," depends upon the properties exhibited by the clays in practice.

In the shallow pits, the reserves of the Old Mine Clay are becoming exhausted and the lower New Mine Clays are, at present, the chief source of refractory clay in the district. Drainage difficulties are being encountered in many of the deeper pits. No coals are associated with the five or more New Mine Clays, in the Stourbridge area. No. 1 New Mine Clay, varies from a useless clay to one approaching in character the Old Mine Clay. It reaches a thickness of from four to five feet. The clays below No. 1 New Mine Clay are inferior to it in quality. In the neighbourhood of Dudley and Gornal, the New Mine fireclays, which underlie the New Mine, Fireclay and Bottom Coals, are the most important.

Fireclays, accompanying the Ganey Coal, are wrought in the Coalbrookdale Coalfield, near Ironbridge, while, from among the clays obtained from the Middle Coal Measures of the Warwickshire Coalfield, near Nuneaton, the most refractory is that from below the Bench Coal.

In the South Derbyshire and Leicestershire Coalfield, fireclays of importance are obtained from near the top of the Middle Coal Measures, at Church Gresley, Swadlincote, Moira and Donisthorpe. The Main Fireclay Seam (Derby Clay) provides a large output of high-grade clay. It is grey, unstratified, tough, saponaceous and, where thickest, usually "fattest" and, where thin, "lean" and sandy. It is fine-grained and uniform in quality and thickness over considerable areas, its usual thickness being from five to eight feet.

At a similar horizon, in the Middle Coal Measures of Flintshire, clays occur which are extensively worked in the neighbourhood of Buckley, where the clay group crops out in three separate strips. The most important clays are the purple, or "Blue Clay," which is mottled, and, frequently, in two beds, with a sandstone parting, and the "Black Clay," which is dark-grey and shaley. Individual beds in the group vary in quality and, as a rule, the clays are rather ferruginous. Middle Coal Measure clays are also worked in Denbighshire.

In Lancashire, common fireclays are obtained near Wigan, from the Yard, Five Foot Pemberton, Four Foot and Trencherbore Seams. Middle and Upper Coal Measure clays are also used near St. Helens and Bolton.

Fireclays are mined at three horizons, in the Middle Coal Measures of Cumberland. The lowest clay, which is, apparently, the Little Main, or Ganister Seam Fireclay, and the highest, which underlies the Fireclay Band Coal, are both worked in the district north-east of Workington, while, in the intervening measures, fireclay above and in the Bannock Band Seam is raised at Whitehaven and Oatlands.

The important Durham fireclays come, principally, from the "Middle" Coal Measures, above and including the Brockwell seam. Most of the fireclays are raised with the coals with which they are associated. From the lower beds at Crook, the Roddymoor, Ballarrat and Five Quarter Seam, fireclays are wrought. Three fireclays occurring, respectively, a few feet above the Brockwell or Main Coal, as

the Constantine Coal underclay and as the Top Main Coal underclay, are mined at North Bitchburn, near Crook and at Rough Lea, near Willington. The clays are mixed as they are raised. The Constantine clay is the best, but the seam contains an ironstone band. The Ballarrat fireclay is, also, of good quality.

The Main or Brockwell Fireclay has been extensively worked. It is best where weathered at outcrop. This fireclay, together with those of the Five Quarter and the Three Quarter Coals, are raised at several pits, near Blaydon and Garesfield, etc. At Hunwick, near Willington, the Busty Coal Fireclay is mined. It is, sometimes, used for mixing with the Brockwell clay.

In the South Wales Coalfield, all the refractory clays are supplied from the Pennant Series and the underlying, Lower Coal Series. In Monmouthshire and East Glamorganshire, fireclays from the lower series alone are worked. The lowest of these are the No. 5 Fireclay of Risca, and a siliceous clay, some distance below the Old Coal at Sirhowy. The Old Coal Fireclay itself is siliceous and is worked near Pontypool. Near Caerphilly, clays underlying the Big Vein and Red Vein Coals are obtained, while three fireclays from above the Elled Coal are used at Ebbw Vale. West of Pontnewydd, Pontypool, the Soap Coal Fireclay, which is eight feet thick and softer towards the top, is worked.

From the lower Series, in the Swansea and Llanelly districts, clays some distance below the Rocket, Little and Red Coals respectively are raised, but fireclays from the Pennant Series are, also, worked. The Gyscwm Rider underclay, two fireclays from below the Black Rock Coal and the highly siliceous Golden Vein underclay, are all obtained within a five-mile radius of Llanelly. At a higher horizon in the Pennant Series is the underclay of the Graigola, Six Feet, or Fiery Coal, which is somewhat siliceous, averages three feet in thickness and is worked near Glais, at Clydach-on-Tawe and at Pontardawe. On the whole, this western part of the coalfield produces fireclays which are more aluminous than those in the eastern portion, but the South Wales fireclays are, in general, siliceous.

Some Coal Measure clays are worked in Scotland, for instance, at Bonnybridge, at Carron Hall, near Falkirk, and near Morningside. The Morningside clay is good, refractory, but fairly hard, and forms the floor of the Lower (or Middle) Drumgray Coal. Of the underclays of several coals, worked in the Kilmarnock district, that of the Wee Coal of Dreghorn is the best.

Mesozoic and Tertiary. These, geologically, more recent clays are, in general, of minor importance for the making of refractory goods, and when used for this purpose are usually mixed with Carboniferous clays. Siliceous clays, from the Upper Estuarine Series (Jurassic) of Castleton, North Cleveland and Stamford, Lincolnshire, and also from the Lower Wealden (Cretaceous), near Fairlight and Hastings, are used for certain refractory purposes.

The Tertiary clays of the Poole district of Dorset and of the Bovey Tracey and Torrington deposits of Devon, contain varieties which are refractory and which exceed in plasticity and binding power, any of the Carboniferous clays. They are, therefore, in great demand as "ball-clay," for mixing with refractory, but non-plastic, or slightly plastic, material.

Decomposed Granite. In Cornwall and Devon, firebricks are made from china-clay rock, or decomposed granite. The waste-products, such as quartz sand, "mica-clay" and the fine sandy residues from the "micas," remaining after the extraction of china-clay from the rock, are utilised for a similar purpose.

SILICA-ROCK.

The "silica" used in the manufacture of silica-bricks is, in every case, a sedimentary rock, composed of grains, or pebbles of quartz held together, more or less firmly, by interstitial siliceous material. Names, such as ganister-rock, "Dinas-rock," quartzite, conglomeratic quartzite, quartz-schist and siliceous sandstone, denote differences in origin, in texture, or in refractory behaviour, and not in chemical composition, of silica rocks. The best of these rock-types contain from 92 to 99 per cent. of silica, low alumina and a negligible amount of fluxing matter.

Silica-rocks are common in this country, in many of the geological formations, from the Pre-Cambrian onward, but the best types are chiefly confined to the Carboniferous.

Pre-Cambrian. A hard, moderately fine-grained, and on the whole, non-felspathic quartzite, belonging to the Mona Complex, is quarried near Amlwch, in Anglesey. In the same county, at Holyhead, a similar sheared quartzite provides refractory material.

Cambrian. Siliceous material, from the Lickey Quartzite, which crops out north-east of Bromsgrove, is used in the Stourbridge clay-producing area.

Some varieties, with over 96 per cent. of silica, of the Hartshill Quartzite, which crops out for about three miles north-west of Nuneaton, are suitable for silica refractories.

Ordovician. In Shropshire, the basal Ordovician, or Stiperstones Quartzite, consisting of thin-bedded siliceous grit, or quartzite, which is sometimes conglomeratic, is quarried on Granham's Moor, Habberley and Nill's Hill, Pontesbury.

Carboniferous, Pre-Coal Measure Rocks. A silica-rock, occurring just below the Calmy Limestone, has been fairly extensively worked at Auckenheath, West Lanarkshire, but the rocks used in Scotland for making "silica" refractory goods are, mainly, obtained from the Millstone Grit Series. In this, they often form part of the Lower and, in particular, the Upper Fireclay groups of the Central Coalfield. The siliceous sandstone-parting between the "Blue" and the "White" clays, is used at Glenboig. So-called ganisters are worked in association with the Upper Fireclay, at Bonnybridge.

In Durham, with Teesdale, Wensleydale and part of Northumberland, the Upper Calcareous Group of the Carboniferous Limestone Series yields silica-rocks at several horizons. They include the Rookhope, Frosterley and Nattrass Gill "pencil"-ganisters and "bastard"-ganisters, and the Coulthard's and Finlay's Harthope, Wensley, Brigg Hazel, Lunedale and Egglestone silica-rocks.

In the three sandstone groups of the Millstone Grit, of Durham, there are two silica-rock horizons in the middle group worked at Love's Sandy Carr, Weatherhill and West Butsfield quarries, and two, in the upper group, worked at Castlehill, near Consett and Cross Quarry, near Stanhope.

The Cefn-y-fedw Sandstone, of carboniferous limestone-Millstone grit age, provides much of the "silica"-stone worked in North Wales. This rock, as quarried at Bwlchgwyn, Minera, Garth, Trevor Rocks, and near Mold, is, at its best, a quartzose-sandstone with subangular grains, often with re-crystallised cement, but with little or no felspathic material. It is pebbly in places. Accessibility, and silica content are the main determining factors in its exploitation.

On the Cheshire-Staffordshire border, thin sandstones, known as "crowstones," often resembling ganister in general appearance, crop out in the shales below the Millstone Grit and have been worked in the neighbourhood of Congleton Edge. Siliceous sandstones from the Millstone Grit are obtained at Ridgeway, near Ambergate, at Meltham, near Huddersfield, and near High Harrington, Cumberland.

In South Wales the Basal Grit of the Millstone Grit Series, is an important source of "silica." It is quarried in Brecknockshire, Carmarthenshire, Pembrokeshire, and Glamorganshire.

Siliceous grits and sandstones, which crop out at the junction between the "Millstone Grit" and the Coal Measures of the Forest of Dean, are quarried near Coleford.

Lower Coal Measures. These measures contain most of the important ganisters and "bastard" ganisters, which are so valuable as refractory materials. The best known of these is the "Ganister," of the Sheffield district, which, with the siliceous fireclay into which it passes vertically or laterally, forms the seat-earth of the Ganister, Alton, or Halifax Hard Bed Coal. This "type" ganister is pale to dark-grey, fine and even-grained, compact and highly siliceous. It is composed of closely-packed subangular quartz-grains, about 0.1 mm. long, cemented together by secondary silica. The rock, which is free, or almost free, from felspar, mica and carbonate, often contains black carbonaceous streaks and breaks with a splintery fracture. It is extensively worked in the Loxley, Don and Little Don Valleys, and also in Derbyshire at Dore, Totley, Chesterfield and Ambergate. Although considerable amounts of ganister have been worked at outcrop, and mined down dip until water has been struck, a large reserve remains.

Other less pure ganisters, siliceous sandstones and grits are worked as well in the Oughtibridge, Penistone and Ambergate areas and, also, occur in the lowest or "Ganister Beds" of the Lower Coal Measures. In Lancashire and East Cheshire, the so-called "ganisters" found in these lower beds are, often, merely

siliceous fireclays. The chief rock of this type is that underlying the Lower Mountain Mine, or Ganister Mine Coal. The Warmden Rock, quarried in the Accrington district, contains enough silica in places to be used as a silica-rock.

The light-coloured, very fine-grained quartzitic sandstones, known in Durham as "pencil"-ganisters, owing to their splintery fracture, come, chiefly, from the lower part of the Lower Coal Measures. These lower beds, also, provide the silica-rocks of Stuartfield Lodge, near Satley, and of some of the Knitsley Fell Quarries. Siliceous rocks, of the nature of impure ganisters, occur near the base of the Coal Measures at Garth, near Trevor, Denbighshire.

Middle Coal Measures. This division of the Coal Measures contains no silica-rocks of repute but rocks, suitable for local requirements, are obtained from it at Pyebridge, in Derbyshire, Buckley in Flintshire, Ketley in the Coalbrookdale Coalfield and Upper Gornal, near Dudley. In the Cumberland Coalfield, impure ganisters, associated with underclays, are extracted economically with the fireclays from the bottom beds of these measures.

Jurassic. Inferior Oolite. The "pencil-ganister" of Commondale and the "ganister" of Commondale and Castleton, in the North Cleveland district of Yorkshire, are used in conjunction with Carboniferous rocks and transported, chiefly, to Weardale and Teesdale.

SAND-CLAY DEPOSITS.

Pocket Deposits of Derbyshire, etc. Deposits, of uncertain age, are worked in pits on the Carboniferous Limestone plateau of South Derbyshire. The depths of the hollows, or "pockets" (probably solution cavities) in the limestone, which contain the deposits are unknown, but, in certain cases, exceed 100 feet. The bulk of the material in most of the pits is a sandy clay, irregularly arranged and associated with variable amounts of white sand, pebbles of quartzite, white or greenish-white highly plastic clay and, sometimes, black clays.

The pits are irregularly distributed within an area some two miles broad by nine miles long extending south-eastwards from Parsley Hay to Brassington. A similar deposit in the Carboniferous Limestone is quarried at Ribden Pits, north-east of Oakamoor, Staffordshire, for making siliceous bricks.

Tertiary Loams and Clays. A yellowish-grey sandy loam, which is obtained with other clays from the Lower Eocene of Surrey, near Ewell and Epsom, is used as a silica refractory. In Devonshire, sands, loams and clays, alternating with one another and associated with Lignite, occupy two depressions, one extending to the south-east of Bovey-Tracey and the other, in the north, near Torrington. Both areas produce ball-clay and pipe-clay.

SILICA-SANDS.

The Leighton-Buzzard district of Bedfordshire and the King's Lynn district of Norfolk, supply most of the high-silicas or "silver" sands, suitable for open-hearth steel furnaces. In both these districts, and in that of Aylesbury, Buckinghamshire, the sands belong to the Lower Greensand (Cretaceous). Considerable quantities are washed to remove thin films of clay-matter from the quartz-grains. Rocks which easily disintegrate are utilised for the same purpose as the "silver" sands. These are obtained from the lower beds of the Millstone Grit and from the Old Red Sandstone in South Wales, and, also, from the Millstone Grit and sandstones of the Carboniferous Limestone Series in Scotland.

DOLOMITE.

The rhombohedral mineral dolomite, possesses a specific gravity of 2.85 and a definite chemical composition, expressed by the formula $Ca\ Mg\ (CO_3)_2$. Geological usage has, however, extended the meaning of the word "dolomite" to include certain calcareous rock-types (limestones) in which more or less of the mineral dolomite is found, in place of calcium carbonate.

Dolomite, in order to be of use as a source of basic refractory material, should contain only a small quantity of excess calcium carbonate. The dolomites worked in Great Britain, belong either to the Permian Magnesian Limestone, or to the Carboniferous Limestone. Bedded dolomites are represented in each of these formations, but much of the Carboniferous dolomite is of secondary origin.

Carboniferous Limestone. At Harboro' Rocks, near Brassington, in Derbyshire, a thoroughly dolomitised limestone is quarried, where it crops out over a large area on the high ground. Dolomitised limestone also occurs in Yorkshire, in the neighbourhood of Grassington.

South of Oswestry, at Porthywaen, near the Shropshire-Denbighshire border, large quarries are worked for limestone and dolomite, while, in South Wales, dolomite is quarried for basic refractory material, at Taff Wells, near Cardiff.

Permian Limestone. In Durham, two quarries, near Coxhoe, work the Lower Magnesian Limestone. In Yorkshire, some of the cream-coloured, completely dolomitised, fine-grained rock is worked in the Magnesian Limestone quarries of Warmsworth Cliff, near Doncaster, as a basic refractory. The Lower Magnesian Limestone is again quarried on the Derbyshire-Nottinghamshire border at Steetley, west of Worksop. The rock is here, cream or pale-buff, fine-grained, sometimes porous, with, practically, no impurities and built up of dolomite crystals averaging 0.1 mm. in length. Dolomite from all the beds, but, particularly from those forming the upper 20 feet of the 30 foot face, is burnt for basic material.

The British output of dolomite for refractory purposes, during 1925, was nearly half a million tons, or 4 per cent. of the total amount of limestone quarried.

Chapter 2.

THE PROPERTIES AND INDUSTRIAL SIGNIFICANCE OF REFRACTORY MATERIALS.

By A. T. Green, F.Inst.P., A.M.I.Chem.E.

The reaction of one scientific study on another is an obvious and well-known cause of progress. Thus, in some measure, owing to the incentive received from the growth of our knowledge of fuel utilisation, the technology of refractory materials has progressed considerably during the past decade or so. However, further research into the problems concerning the manufacture and industrial usage of refractories is imperative, since the more precise our knowledge of these materials, the greater will be fuel conservation and the economy of high-temperature operations.

The correct selection of materials for specific duties is essential to industrial economy. Herein, lies the value of specifications. Such criteria, although usually, they cannot adequately circumscribe the conditions of use, give valuable guiding information. In order to formulate specifications initial correlation of data, preferably of a fundamental nature, is carried out. In the case of clay technology, much of this knowledge is incomplete so that the specifications for the selection of refractories are neither elaborate or rigid. Nevertheless the work of certain bodies, notably the Institution of Gas Engineers and the British Refractories Research Association, has added considerable definition to certain aspects of this subject. But, that stage of the science of selection, which has for its basis the adequate appreciation of fundamental properties of clays and allied materials is not here, yet.

It must be emphasised that correct compromise is the keynote of successful selection. In making a choice, it is first essential to have a thorough knowledge of the circumstances governing the industrial usage of the material. It is, also, desirable to fix a minimum economic life for the refractory structure, for this is a most important factor in the determination of the durability of the materials of construction. With this knowledge in mind some definition of (a) the structural stability of the refractory at high temperatures; (b) its resistance to disintegration, corrosion and erosion governed by considerations of the particular conditions of use; (c) its thermal properties, should be obtained. Unfortunately, in the main, these properties cannot be stated in precise terms, with the result that empiricism, at the present time, plays a conspicuous part in the selection. Again, the commercial aspect must be considered, for an appreciation of the technical attributes of a product will, of necessity, be tempered by considerations of cost. A super-refractory may show a much more desirable compromise of properties for a particular duty than a fireclay or silica product. In such circumstances, the overall cost per unit of work done is the deciding factor. It is such a factor which determines the exceptional value of the commoner products—fireclay and silica goods—in industrial operations.

THE CONSTITUTION OF SILICA AND FIRECLAY PRODUCTS.

Silica products.

Quartzitic rock, i.e., ganister, forms the usual basic raw material used in the manufacture of "straight" silica bricks. Such rock is crushed, ground, graded, mixed and "tempered" with lime emulsion, so that the final product contains about 2 per cent. of lime. After moulding into shape the products are dried and fired to high temperatures in the vicinity of cone 16 (1,460°).

The texture and, in some measure, the final constitution of a silica product is determined by the grading of the original raw material. In fact, there is an immense field for investigation in the problems connected with the influence of grading on the constitution and successful usage of such materials.

In general, it is found that a brick of "fine" texture is more effective in the "carbonising" industries, whereas a coarser material finds greater favour in the steel industry. The mechanical strength of the material depends on the angularity of the coarser fragments, the amount of the fine fraction and the firing treatment. Under the influence of continued high temperatures, over 1,000° C., quartz may be transformed into either or both of two other forms, i.e., tridymite and cristobalite. These changes are

accelerated by the presence of a flux, such as lime, which is the common agent used in the manufacture of silica bricks. Thus, in any well-burned, lime-bonded silica brick, the presence of tridymite, cristobalite and quartz, together with 5-15 per cent. of a glassy matrix of a complex calcium alumino-silicate, must be considered. The most effective firing of " straight " silica bricks aims at the total elimination of quartz, and as far as is compatible with the cost of continued firing, the production of an excess of tridymite. It must be mentioned, however, that the hardest firing is not always the correct one for the production of a product for a specific duty. For coke-ovens and gas-retorts those silica bricks which have received hard firing are certainly the most successful.

The elucidation and quantitative expression of the constitution of a silica brick is not a simple matter. There is, however, a fair amount of data, which can help in the formulation of an impression.

The specific gravity of quartz is 2.65, of cristobalite 2.32, and of tridymite 2.28. Any straight silica brick, then, which has a true specific gravity of over 2.50 is poorly fired and contains a large proportion of unconverted quartz. The medium fired product has a specific gravity of 2.45, and, in consequence, contains an appreciable quantity of quartz, together with some cristobalite. In the high-grade product, which has a specific gravity varying from 2.32-2.37, the quartz content has been reduced to a practical minimum. These bricks, however, contain variable quantities of tridymite and cristobalite, a fact which plays a conspicuous part in the spalling tendency at low temperatures.

Table I. gives some of the analytical and physical data concerning well-known brands of British silica bricks.

TABLE I.

Mark.	Analysis.			Physical Data.		
	SiO_2	Al_2O_3	CaO	True Sp. Gr.	Apparent Sp. Gr.	True Perc. Porosity.
A	95.80	1.18	1.46	2.336	1.69	27.9
B	95.00	1.58	2.34	2.319	1.60	31.0
C	94.68	1.26	3.20	2.327	1.40	39.8
E	95.04	0.83	1.62	2.356	1.71	27.6
F	94.20	1.80	1.48	2.438	1.73	29.1
G	91.50	5.87	0.34	2.52	1.90	26.1
H	94.54	2.93	1.35	2.371	1.66	30.1
I	95.40	1.74	1.54	2.345	1.53	34.8

Micro-examination and other data have indicated that B and C contain high percentages of tridymite, whereas A, H and I contain large cristobalite developments. This is interesting in the light that B and C contain large amounts of lime and show the greater development of matrix. Further, there can be little doubt that these products have received very effective heat treatments. While it is unsafe to generalise, the present author has noted that the larger amounts of lime together with effective firing have usually resulted in the promotion of tridymite growths, a structure desirable in that it forms a net-work of acicular crystals with very good binding properties and resultant strength. Naturally, there is a limit to the amount of the lime addition, for otherwise, with excessive additions the product softens at the high temperatures of industrial use. Modern research work has shown that there are a number of other binding materials, which can effectively " catalyse " the transformation of quartz into the " low specific-gravity " forms of silica. Such substances as biotite, borocalcite, ferric oxide, have received laboratory investigation in this connection by Wood, Houldsworth and Cobb, and others, and the results are worthy of experimentation on the industrial scale.

It has been shown by W. J. Rees that ferric oxide, when present in controlled amounts, while having no appreciable effect on the refractoriness of a silica brick increases the tridymite formation and resultant strength to a remarkable degree. Rees, therefore, suggests the addition of specific amounts of ferric oxide to those bricks which are to be used for steel furnace work.

The determination of the variation of the coefficient of thermal expansion of a silica brick with temperature gives some indication of its constitution. There are, of course, limitations to the inferences, which can be drawn from expansion determinations, since there are factors, which are, at present, indeterminate. Quartz, cristobalite and tridymite are themselves capable of existing in more than one form. The changes or inversions from one form to another, i.e., from the α to the β state, take place in a reversible manner at relatively low temperatures.

These changes are associated with very appreciable volume alterations, the larger of which, according to some investigators, amount to 3 per cent. of the original volume of the brick. Such inversions may cause severe strains in the product, ending in final disrupture. The following table gives data concerning the reversible expansions under consideration:—

TABLE II.

SiO_2 Modification.	Increase in Volume (V). Increase in Length (L).	Investigator.
α to β quartz. 575°C.	0.45% (L).	Fenner.
α cristobalite to β cristobalite. 225°C.	1.0% (L). 3.5% (V). 2.0% (V).	Fenner. Spotts McDowell. Endell & Rieke.
α tridymite to β tridymite. 117°C.	0.15% (L). 0.30% (V).	Fenner. Spotts McDowell.
α_1 tridymite to β_2 tridymite. 163°C.	not accurately ascertained, but comparatively small.	

The data in this table shows the appreciable differences in the volume changes of the three changes, and indicates that a measure of such expansions must give some information respecting the relative amounts present in a particular material. The present author has completed some work on this aspect considering the tridymite and cristobalite changes, but not the quartz. Figs. 1 and 2 indicate some of the results obtained, while Table III. is an analysis of these results.

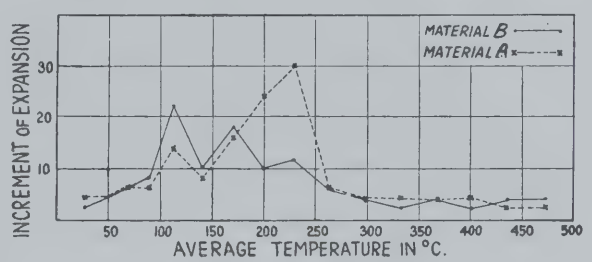
TABLE III.

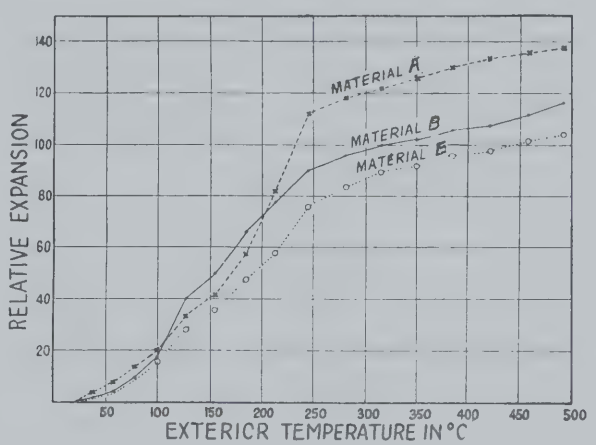
Nature of Expansion.	Surface Temp. Range.	Relative Expansion.							
		A	B	C	E	F	G	H	I
Tridymite	100°-184°	38	50	40	30	32	8	36	32
Cristobalite	184°-279°	60	28	26	40	36	10	42	50
Total expansion for experiment.	15°-490°	140	118	108	112	106	38	118	122

Amongst the indications of this table, it is noted that B and C contain high percentages of tridymite, while A and I show a preponderance of cristobalite. These facts have been further emphasised by microexamination. A greater definition of the matrix of silica bricks is, however, essential before the results of expansion data can give unqualified conclusions respecting the constitution.

Fireclay Products.

Fireclay is a comprehensive term, including a large variety of substances differing to a considerable extent in both constitution and physical properties. F. R. Ennos and A. Scott state that " refractory and semi-refractory clays consist, essentially, of hydrated forms of silica and alumina, which may be either free or combined." The commonly accepted formula for clay substance is Al_2O_3. $2SiO_2$. $2H_2O$. Besides this compound, fireclay contains variable quantities of accessory minerals including quartz, micas, felspars, iron and lime bearing minerals. As a matter of convenience, it is desirable to consider the constitution of fireclays in terms of clay substance, quartz, felspathic, micaceous, ferruginous (ferrous and ferric), calcareous and carbonaceous substances. Such a conception helps in comprehending many phenomena associated with the firing and ultimate properties of fireclay products, including the vitrification, the colour and formation of iron " blebs " and patches and the texture of the finished product. In the manufacture of firebricks, the raw materials are subjected to preliminary treatments including mixing, grinding, screening and tempering. Depending on the nature of the clay, varying quantities, usually between 15-25 per cent., of graded grog (prefired fireclay) generally, the very fine size is eliminated—are added and this worked into the clay in order to obtain a homogeneous mixing. This initial treatment is of great importance to the properties of the finished product, in fact if it is inadequate the texture of the brick may be ruined. For instance, a laminated texture is particularly objectionable, since a product possessing it is liable to spalling trouble. The fireclay shapes, being properly dried, the product is fired according to a predetermined schedule. The principle of the firing operation is to produce from a satisfactory manufactured and dried clay shape a finished product possessing strength, shape and such general and particular properties as fit it for its subsequent duties. Since hardly any two fireclays are the same in their behaviour towards firing and since the selection of refractories necessitates different properties for different duties it must seem that the firing operation is not capable of acute standardisation. However, there are certain features connected with specific periods in firing which afford guidance in controlling this operation to some degree. The first period, known as the water smoking period, is concerned with the expulsion in a kiln of mechanical and hygroscopic water together with the colloidal water associated with halloysitic clays, contained in the dried but unfired goods. The final period of firing ranging from 850° to the finishing temperature is known as the vitrification range. Vitrification may be defined as the progressive partial fusion of the various mineral constituents of the fireclay chiefly including felspathic, calcareous, and ferruginous substances, which is governed amongst other factors by the composition of the body as a whole, the size of the grain and the structure of the ware, for which the clay is desired. In fact, the object of the heat work during this period is the production of a suitable amount of vitrified or glassy material, which will surround the remaining particles, and fill the interstices to a suitable extent, dependent on the properties desired in the finished product. An examination of analyses indicate that fireclays contain clay substance and " free " silica in very variable quantities. It has been suggested that fireclays may be divided in three categories, (1) " normal " with an alumina content between 36-39 per cent.; (2) aluminous,





FIGS. 1 AND 2.

containing over 39 per cent.; (3) siliceous containing less than 36 per cent. Al_2O_3. The " siliceous " firebrick is by far the commonest category, and it is often taken to include that variety of product, in which quartz is added as an addition or reinforcement. Siliceous fireclays contain free quartz varying in grain size from sub-microscopic particles to grains of appreciable magnitude. After the moderate kiln firing to which fireclay products are subjected, much of this quartz may remain as such embedded in the matrix or supporting structure of the fired product. Depending on the duration of the fire the size of the grain and the nature of the matrix, some of the quartz may be transformed into cristobalite. It does not necessarily follow, however, that high quartz content in a raw material signifies high quartz or cristobalite contents in the fired product. Much depends on the grain size, the amount and distribution of the fluxing materials, and the firing procedure. Such quartzitic material goes into solution in the viscous flux during vitrification and remains in this state after cooling. Dissolved quartz behaves rather as silica glass and does not show the characteristic expansions of quartz and cristobalite.

A siliceous firebrick then may contain either (1) free quartz; or (2) free quartz and cristobalite; or (3) little or no crystalline silica. The last class is not a conspicuous one. Finally, a fireclay product may contain mullite, quartz, cristobalite, corundum (derived from excess alumina) and a matrix of vitrified material.

Texture of fireclay products.

The texture of a fireclay product is controlled by (1) the grain size of the clay, (2) the nature and grading of the grog addition, (3) the extent of the firing operation. Fineness of grain favours vitrification and so reduces the refractoriness or heat resisting capabilities of the material. Consequently, it may be taken as axiomatic that the coarser the texture of a firebrick made from an individual fireclay, the higher its softening temperature.

Grog may be regarded as burnt fireclay or ground firebrick, which is mixed with fireclay to serve as a skeleton to facilitate drying, to control the contraction during drying and firing, and to modify the behaviour of the refractory material when in use. The meaning of the term grog is also extended to include non-plastic materials other than burnt fireclay. Grog behaves as an independent constituent and is fixed in the brick by the fluxes of the surrounding clay. The tendency of the coarse-grained brick to crack and split with abrupt changes of temperature is much less than that of a fine-grained product. The crushing strength and tenacity of a coarse-grained brick are, however, always low. Thus, retorts, with a feeble tensile strength are very friable and readily disintegrated by shocks, abrasion and such-like actions. The pores of the coarser products are, in general, large, with the result that flue dust and slag penetration rapidly take place in practice. Thus, it appears clear that such antithetical properties often being desirable, it is necessary to effect a compromise.

STRUCTURAL STABILITY.

The changes which occur during the firing of refractory materials belong to a class known as arrested reactions, in which the chemical and physical stages are stopped before they have gone to completion. During the firing of firebricks, for instance, the actions taking place result in a certain amount of contraction. If these actions are not sufficiently completed this contraction may continue to occur during use. If such after-contraction is considerable, the masonry of the furnace will certainly be displaced when the bricks are in use, holes and distortions resulting. The laboratory test of heating the pieces to temperatures of 1,350° or 1,410° gives an indication of the amount of contraction likely to occur. By this test, a linear after-contraction of 1.0 per cent. or over for a fireclay product is regarded as showing the material to be quite unsatisfactory for more particular uses.

No product should show more than 1 per cent. linear expansion after heating to and holding at cone 14 for two hours. Expansion spaces are allowed in the construction of silica installation. In some instances, owing to the inadequate firing of the product, this procedure has been found insufficient, and disintegration of the masonry has resulted from the immense expansion strains put into the structure.

Refractoriness.

The term refractoriness implies the resistance of a refractory material to softening or partial fusion when heated. It has been clearly recognised for some considerable time that the softening of clay is not a specific property analogous to true melting, but that it involves both temperature and time factors. A definite size of cone (2in. in height and $\frac{1}{2}$in. side for the triangular base), ground to the same shape as a seger cone is used as the test piece. This is cemented on to a slab (usually bauxitic) and surrounded by seger cones of definite significances. It is placed in a furnace, whose temperature is raised by 10° per minute and the atmosphere maintained oxidising. The result is adjudicated either on the squatting of the material or its condition when a specific seger cone bends. Some laboratories observe the seger cone which is bending as the material bends and take this as the indication of the "squatting temperature" or the refractoriness. Others observe "signs of fusion" at a specific point in the heat treatment. Such signs adopted are (1) angular edges of the material beginning to lose their angularity; (2) piece showing signs of bending; (3) matrix showing signs of running out. Although there are decided discrepancies between the results of the two tests, observations based on either the one or the other give a good guide in the selection of refractories. The refractoriness test, although useful, gives no certain indication of the effect of temperature and pressure acting together. Naturally this duplex effect is the all-important consideration in high temperature structural work. The study of the refractoriness-under-load has proceeded for the past twenty years, but the early work of J. W. Mellor has led to the present accepted procedure. More recently, A. J. Dale has developed this test to a high degree of proficiency, obtaining data of fundamental importance. L. Bradshaw and W. Emery determined the refractoriness and the under-load value of fire and silica mixtures between the limits of 100 per cent. of each. Table IV. shows the data. There is a minimum round about 60 per cent. silica. The higher the silica content above this, the less is the effect of stress on the squatting temperature. In highly grogged fireclay and generally in silica products, failure in the test is not so much due to viscous squatting as to a reduction in mechanical strength and failure by shear along definite planes. Dale states that "furthermore it became obvious that the temperature of complete collapse under load was in many cases a very indefinite and necessarily arbitrary point, being preceded by a gradually accelerating subsidence over a wide range of temperature." This is the crux of Dale's more recent researches.

TABLE IV.

% Firebrick.	% Silica Brick.	Ordinary Refractoriness in cones.	Cone of collapse, under load of 35 lbs./sq. in.
100	—	33	20
60	40	28	19
50	50	20/26	18
40	60	19/20	16/17
30	70	20	17/18
15	85	28/29	20
—	100	31	29/30

The above figures show, definitely, the stability of silica under the combined action of load and temperature. The rigidity of the product is maintained up to the point of collapse. This is 300° higher than the safe temperature of operation of the other materials. It is therefore unlikely that silica will be burned down under normal carbonising conditions.

By means of a lever system, it is possible to measure movement of the test piece during the load test. The data so obtained has given valuable information concerning the probable behaviour of refractories in practice, and has elucidated many points of practical import. The following is a brief résumé of the conclusions drawn from this work. With commercial silica bricks containing unconverted quartz, under a

load of 75 lbs. per sq. in. failure began at 1,500° and total collapse ensued at 1,570° owing to mechanical stress. Under a load of 4 lbs. per sq. inch, the brick stood up until squatting resulted from softening of the matrix. Brick containing much unconverted quartz are liable to disruption under high external loads at temperatures above 1,250° to 1,300° unless a specially elastic matrix is present. In Dale's work, a silica brick containing quartz, but with a bond exceptionally rigid at high temperatures, did not begin to show subsidence until 1,670° and total collapse did not take place until 1,710°-1,730° was reached. With commercial silica bricks, containing a large percentage of cristobalite, under a load of 4 lbs. per sq. in., the highest temperature attainable in the load test furnaces was reached without showing any abnormal expansion at high temperatures, and under a load of 50 lbs. per sq. in., appreciable deformations did not begin until 1,700°, and the brick failed between this temperature and 1,730°. A rapid expansion occurred between 200° and 350°, but this expansion was much less under the greater load. In the case of commercial silica bricks, with good tridymite development, failure under high load may occur below 1,600°, but if a matrix of moderate viscosity be present the brick may withstand even higher temperatures. No particularly marked rapid expansion takes place at low temperatures.

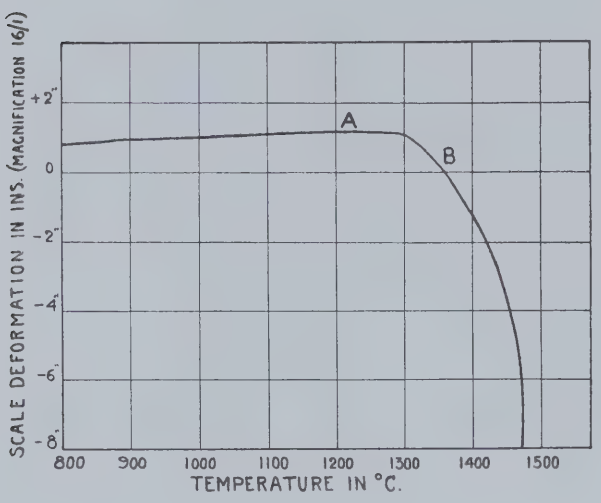


FIG. 3.

In general, silica bricks show a mechanical fracture in contrast with a squatting or viscous deformation, which is the usual mode of failure of fireclay products. Fig. 3, due to Dale, shows the general mechanism of the subsidence for firebricks. The consideration of the data collected shows that attention should be directed to the range AB. Below a temperature approximating to A (the point at which marked flattening of the curve becomes noticeable) deformation under loads incurred in actual practice will be small. Within the range (1,200°—1,350°) deformation both in rate and in quantity is governed by the actual temperature and load values. In certain cases, the deformation may be excessive. Above temperature, corresponding with the point B, excessive deformation can occur under low loads. Thus the determination of the subsidence curve for fireclay goods gives a valuable clue to their likely behaviour in the circumstances of their industrial usage. Further, it shows that the temperature of complete squatting is not a safe criterion to the industrial efficiency of these products. Amongst many other features, of this work, the influence of grog has been considered. It is stated that there is a limit to the amount of grog which can be incorporated in a firebrick, and information regarding this limit can be deduced from the modified under-load test. When non-porous or excessively vitrified grog is used, failure is mostly by rupture. With a moderately porous grog, a pre-soaking in water of the grog particles leads to increased resistance to deformation at temperatures below that of rapid collapse. With 40 per cent. or more of vitrified grog, large particles size tends to cause premature failure under stress at high temperature, chiefly by rupture round the large grog particles.

Spalling.

The resistance to spalling of refractories plays a great part in their successful durability in industry. Spalling can be regarded as the failure of a refractory to withstand without disrupture those stresses induced by temperature fluctuations or thermal shock, under the general and special conditions of industrial usage. At least three factors are involved. These are (1) the rate of change of temperature which can be effected under definite conditions in the interior of a refractory mass; (2) the elastic and viscous properties of the material; (3) the nature, and extent of the volume changes set up by rapid fluctuations

of temperature. The first factor is defined by the coefficient of temperature diffusivity of the material, together with measurements respecting the size and contour of the mass. The second is exceedingly difficult of definition, while the third can be adequately circumscribed by a study of the thermal expansion and the velocity of those changes involving expansions observed in the constituents of the refractory product.

F. H. Norton has recently evolved a formula based on considerations of homogeneity, circumscribing the spalling tendency of refractories, and similar to the well-known formula of Winklemann and Schott for the thermal endurance of glass. This is written $S = \frac{E}{F \cdot K^{\frac{1}{2}}}$ where S = spalling tendency, E = coefficient of thermal expansion, F = the maximum shearing strain, K = the coefficient of temperature diffusivity. The maximum shearing strain or "ultimate strength" factor is not in itself truly elementary, but is rather a function of elasticity, viscosity and a heterogeneity factor, the last-mentioned including the extent and nature of vitrification and porosity.

Up to the present, the laboratory testing of spalling tendency has consisted in slowly heating either the whole or the end of a refractory shape, i.e., a smaller cube or a standard sized product to a relatively high temperature, and noting the effects of different rates of cooling, and the number of quenches required to spall the specimen. Using such a method, Norton endeavoured to check the efficacy of his formula for firebricks. Table V. shows some of the results and indicates an apparent consistency.

TABLE V.

Mark.	F_1	$E \times 10^{-6}$	$K^{\frac{1}{2}}$	$\frac{E}{F_1 \times K^{\frac{1}{2}}} \times 10^{-7}$	Number of Quenches.
1	0.144	51	6.2	72	26.5
2	0.050	50	6.3	157	23.0
3	0.052	39	6.5	115	24.0
4	0.057	53	6.5	143	15.6
5	0.032	37	7.3	159	15.0
6	0.107	133	6.3	197	8.4
7	0.094	405	6.7	644	0.3
8	0.032	116	6.4	567	2.4

The coefficient of thermal expansion for firebricks, shows considerable variation for different products. In illustration of this, Norton obtained values varying from 50×10^{-7} to 133×10^{-7} in C.G.S. units for the average value of this constant at 500° C., while M. C. Booze and S. M. Phelps obtained even greater variations. This fact is of the highest importance in structural work and may account for many of the structural weaknesses noted in furnace and kiln construction, for which there is, otherwise, no apparent explanation. This variation appears to be connected with two variables, viz., the amount of firing and the constitution of the original clay. It is now an established fact that products high in alumina have, in general, low coefficients of reversible expansion, while those high in silica often have high values for this property. In some instances, continued firing seems to increase the thermal expansion, in others, to decrease it. It has been stated that the lowest value for the coefficient of thermal expansion was obtained from a test piece which had been fired to an extremely high temperature. This firing treatment, in all probability produced an excessive amount of vitrified or glassy matrix, which, as such, possesses a comparatively low value for the constant in question. Steger investigated the behaviour of a Grossalmerode crucible clay, containing 73 per cent. SiO_2 and 17 per cent. Al_2O_3, after repeated firings, and Table VI. shows the expansion data determined on this material after different heat treatments.

TABLE VI.

Firing Treatment.	Thermal Expansion for the Temperature Ranges.			
	15°-300°	300°-500°	500°-600°	600°-750°
Burned at 900°	60×10^{-7}	95×10^{-7}	242×10^{-7}	18×10^{-7}
1,250°	160	110	230	35
1,450°	322	52	55	45

A study of this table shows that the reversible expansion due to cristobalite taking place at 210°, has been increased at the expense of that due to quartz, taking place at 575°, by increased heat treatment. In other words, the quartz has been converted to cristobalite with a consequent increase in the spalling tendency of the product. Further, the actual conversion itself can set up strains in the product, causing local weakness, which predisposes the material to spalling.

By reason of the constitution of and consequent peculiar expansions at definite temperatures (Tables II. and III.), silica products are particularly prone to spalling at both low and high temperatures. In modern coke-oven construction only highly converted silica products are used, consequently it is absolutely necessary that the rate of rise of temperature up to 700°—800° be very slow and carefully controlled, otherwise disruptive action will take place in the wall. Apart, however, from the low-temperature spalling effects, the high-temperature changes are equally important. Practically the whole of the silica bricks supplied to industry contain unconverted quartz. During high-temperature working, there is a gradual transformation of this to the low specific gravity forms with consequent expansion. Unless conditions are so arranged that this expansion can be adequately encountered, destructive strains must be set up with predisposing circumstances to failure. Thus in the design of high-temperature installations, allowances, based on test and other data, must be made for the probable expansion in use.

THERMAL PROPERTIES OF SILICA AND FIRECLAY PRODUCTS.

The problem of fuel economy has given considerable impetus to the study of the thermal criteria of refractories. The heating efficiency of much high-temperature work cannot be computed without those quantitative data, which measure the fundamental thermal properties of refractory products. Then, again, improvement in the technique of many industries has made it apparent that refractories must be divided roughly, into two groups, i.e., conductors and insulators. The gas retort or coke-oven wall is the more efficient, the more quickly the heat is transferred through it, and the greater the ease with which the desired temperature is attained on the carbonising face; while the more nearly the blast furnace lining approaches a perfect thermal insulator, the greater is the heat conservation during the smelting of iron. Consequently, definite quantitative expression concerning the properties of specific heat, heat capacity, temperature diffusivity and thermal conductivity, surface emissivity of refractories is a vital necessity to the well-being of high-temperature industries. Much of this knowledge is, at present, uninvestigated.

Specific heat.

The specific heat, since it measures the amount of heat required to raise 1 gram of the substance through 1° C., is the essential factor in calculating the amount of heat taken up by a furnace structure during its use. Thus, L. Bradshaw and W. Emery have computed that it requires 94 lbs. of coal (calorific value 8,100 lbs. calories) to raise the temperature of 1 ton of firebrick from ordinary temperatures to 1,200°. A. T. Green has also shown that to raise the temperature of a construction, i.e., a furnace containing 100,000 bricks, to an average temperature of 500° a minimum of 7 tons of coal is necessary.

The specific heat of fireclay and silica products at ordinary temperatures has received a fair amount of attention. S. T. Wilson, A. D. Holdcroft and J. W. Mellor showed that the specific heat of firebrick increases very rapidly with temperature and that $S=0.193+0.00006t$ circumscribes the data for the

mean specific heat between 0° and t° C up to a temperature of 1,300°. L. Bradshaw and W. Emery using a similar method, with additional elaborations, obtained the relationship $S=0.193+0.000075t$ for the variation of this constant with temperature between 25° and t° C. up to temperatures of 1,400°.

Apparently, no relationship between the constitution and specific heat of firebricks has been found to subsist. In this connection it is interesting to note that little difference is found between the specific heats of fireclay products and silica materials. With the object of giving a suggested value of the specific heats of fireclay and silica products at definite temperatures, Table VII. is appended. This table is based on the work of Bradshaw and Emery, and Heyn and co-workers.

TABLE VII.—SPECIFIC HEAT OF FIRECLAY AND SILICA PRODUCTS AT DEFINITE TEMPERATURES.

Material.	Specific Heat at						
	200°	400°	600°	800°	1,000°	1,200°	1,400°
Firebrick	0.213	0.245	0.278	0.304	0.314	0.323	0.332
Silica Brick	0.219	0.253	0.279	0.298	0.312	0.324	0.334

A study of the investigations concerning the specific heat of silica bricks of different constitutions does not appear to show any great differences in the values of this constant.

The heat capacity gives an idea of the relative amounts of heat absorbed by structures of different refractory materials (Table VIII.). For a non-porous body it is the product of true specific gravity of the body and its specific heat, but since all refractory materials are, more or less, porous, actually it is the product of the apparent specific gravity and the specific heat. Both the apparent specific gravity and the specific heat vary with temperature, and, consequently, although the apparent specific gravity slightly decreases with temperature, it is easily shown that the heat capacity per unit volume increases rapidly with temperature.

TABLE VIII.—HEAT CAPACITIES.

Temperature.	Firebrick.	Silica Brick.
100°	0.400	0.349
1,000°	0.570	0.495

It may be interesting here to consider the influence of firing treatment on the apparent specific gravity and, therefore, on the heat capacity of fireclay and silica products. The apparent specific gravity is dependent on the true specific gravity and the percentage porosity according to the formula $S_a=S_t\left(1-\frac{P}{100}\right)$ where S_a is the apparent specific gravity, S_t the true specific gravity, and P the true percentage porosity. Thus, assuming that the porosity remains constant, any treatment which alters the true specific gravity will have an effect on the apparent specific gravity. In the maturing stages of the firing the true specific gravity of silica products may fall from 2.65 to 2.30, particularly if the firing is prolonged in order to obtain the full effect. Superior silica products thus have comparatively low apparent specific gravities and, in consequence, comparatively low heat capacities.

In general, the true specific gravity of fireclay material is only slightly altered by combined heat treatment in the range of maturing temperatures. Usually this alteration is a decrease, which has been given some quantitative significance by the present author. Thus, the true specific gravity of a fireclay product may decrease from about 2.63—2.61 and maintain the shape together with other desirable properties of a well-burned material. This alteration in true specific gravity is almost invariably of a small order and, consequently, has little effect on the apparent specific gravity assuming, of course, that the porosity is constant. However, with increasing vitrification of a fireclay there is always a tendency

towards and in most cases a realisation of a decrease in porosity with consequent increase in apparent specific gravity. Thus, continued heat treatment in the vitrification range (up to a certain point) increases the apparent specific gravity of a fireclay, and a well-burned fireclay product has a relatively high apparent specific gravity ranging from 1.8—2.2. Further, the heat capacity of fireclay products is decidedly greater than that of silica products.

Temperature diffusivity and thermal conductivity.

The temperature diffusivity may be, broadly, considered as that property which controls the velocity of propagation of temperature, in a mass of refractory material. The coefficient of temperature diffusivity may be said to express in C. G. S. units the rise in temperature produced in 1 c.c. of a substance by 1 calorie, in 1 second, through 1 sq. cm. of a layer 1 cm. thick having a temperature difference of 1° C. between its faces. This conception has a particular value in those systems in which temperature is of more significance than total heat, i.e., the coke oven and the gas retort. In fact, in considerations of the carbonising face temperature diffusivity measurements are of great importance.

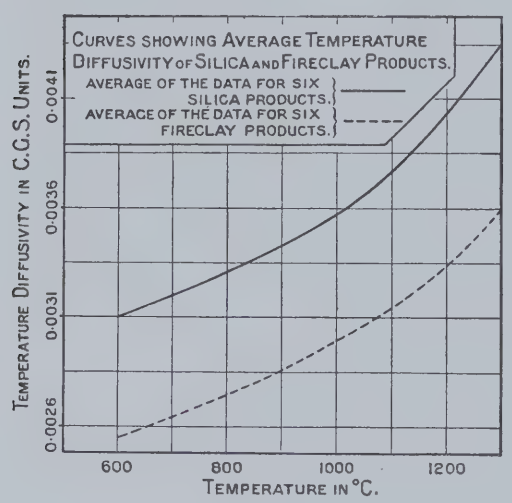


FIG. 4.

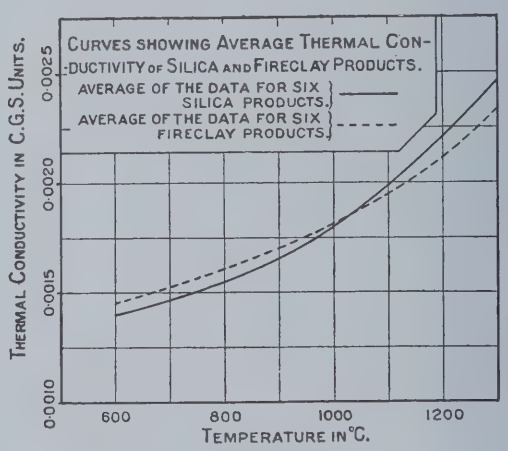


FIG. 5.

The reported values of the coefficients of temperature diffusivity and thermal conductivity seem to depend on the nature of the adopted methods, consequently there is a wide variation in the data available. The methods of measuring the thermal conductivity of refractory materials which are based on Fourier's equation for linear diffusion essentially determine the coefficient of temperature diffusivity. Using such a procedure E. Heyn gives 0.0032, at 1,000° C., A. T. Green, 0.0040, at 1,000° C., and Y. Tadokoro, 0.0142, at 900° C., for the temperature diffusivity of a silica brick, and Dougall, Hodsman and Cobb, with the calorimetric method, give the values for the temperature diffusivity of a firebrick at 500° as 0.0055, at 1,000°, 0.0068, and for silica brick at 500° 0.0053, at 1,000°, 0.0088.

In considering the factors influencing temperature diffusivity the following points are of interest: (1) The temperature diffusivities of fireclay and silica products increase with temperature; (2) Increased firing treatment increases the value of this coefficient for both silica and fireclay bricks. This fact is particularly marked in the case of silica materials; (3) A high porosity is not inimical to low diffusivity. Measurements indicate that at low temperatures with increasing porosity decreasing temperature diffusivity is to be expected, while at high temperatures the reverse phenomenon often holds good. In general, it appears that the rate of increase of temperature diffusivity with temperature at high temperatures is greater in the case of materials of high porosity.

In defining "thermal conductivity" it is essential to consider a uniform plate with parallel walls, such that one face is maintained at a temperature θ_1 and the other face at a temperature θ_2. Suppose the quantity of heat Q passing through the plate in a time t is necessary to maintain the two faces at the above temperatures. Then, if the thickness of the plate is x, and the area is A, $Q = k\left(\frac{\theta_1 - \theta_2}{x}\right)At$ where k is an assumed constant depending on the nature of the substance and is known as the coefficient of thermal conductivity. In the determination of this constant much work has been done by methods depending either on the application of the above formula or on mathematical analysis. There is not, however, good concordance between the results of various investigators.

The following notes form a consideration of the factors influencing the thermal conductivity of silica and fireclay products :—

(1) The value of this constant for a specific product increases with temperature.

(2) In recent years, there has been considerable discussion concerning the relative merits of silica and fireclay refractories as conductors of heat. This discussion, which has arisen from the increasing use of silica in coke-oven and gas retorts constructions has been based on assumed practical experience, without reference to the actual determinations of the coefficients of thermal conductivity of these materials. The opinion has been consistently expressed that silica brick is a better conductor than firebrick. From the early investigations of the present author, this statement did not seem to be fundamentally true. In fact, so much variation was found between individual products, that it appeared definitely incorrect to assert that, one material was better than another without the evidence of a test. The present position seems to be that, comparing superior products of each kind, there is little to choose between the two types at low temperatures (900° or so). However, since the rate of increase of conductivity with temperature is greater in the case of silica brick, the conductivity of this product, at high temperatures is, in general, greater than that of fireclay goods. However, the temperature diffusivity of a well burned silica product is, on an average, definitely greater than that of a fireclay product, particularly at higher temperatures, a fact, which appears to account for the reputed effective thermal properties of silica refractories in the carbonising industries. A study of Figs. 4 and 5 will illustrate this point of view.

(3) From S. Wologdine's and the present author's work, it appears that increasing the firing heat treatment within the limits of the production of a commercial product, increases the conductivity of both silica bricks and firebricks. The thermal conductivity of poorly fired silica brick is particularly low. The presence of a large excess of cristobalite in a silica brick appears to favour the conduction of heat. Fig. 6 illustrates the increasing conductivity of fireclay with increasing firing treatment. Here, conductivity data is plotted against true specific gravity values, these latter indicating heat work, for the lower the specific gravity the more effective the heat treatment has been.

This argument appears to lead to the conclusion that under the influence of industrial usage, the thermal conductivity of these products will increase. The present author investigated this problem on a semi-silica material, containing 80 per cent. of silica, which had been in use for fifteen years together with samples of the unused product. It was found that the thermal conductivity of the used product was much greater than that of the unused brick.

(4) The influence of porosity on the thermal conductivity of a refractory material, has received considerable attention. It has been suggested that there is a relationship between thermal conductivity and porosity. While such a statement cannot be refuted (for, in part, it must be true) its limitations should be frankly recognised. In so far as the pore-spaces act as insulators, thus impeding the passage of heat, they have an influence on thermal conductivity. The term percentage porosity is used to indicate a measure of the pore-spaces, which, naturally vary in size from easily-perceptible fissures to microscopic holes, many sealed off from the mass. The property of "pore-space" insulation depends on many factors, including temperature and the disposition, size and shape of the pore-spaces. Now, since the measurement of percentage porosity does not include knowledge of these factors, a quantitative relationship between porosity and thermal conductivity cannot be anticipated.

It has been stated that the transference of heat through the pores is very small compared with that transmitted through the solid matter, or in other words, pore-spaces consistently maintain insulating properties. It would thus follow that the higher the porosity of a refractory material, the greater ought its insulating effect to be. This argument appears to be justified by the fact that such highly porous materials as diatomaceous earth bricks possess pronounced insulating properties at lower temperatures (i.e., up to, at least, 700° C.), and thus, under the accepted conditions of use. However, some investigators, notably, J. W. Mellor, have as the result of practical observations and theoretical deductions suggested the hypothesis, that, at high temperatures, heat may be transmitted by way of the pores, at a rate which is comparable with heat of conduction through the solid matter. In the earlier work of the present author, two facts seem to bear out this hypothesis. In the first place, the pronounced rates of increase in the value of the coefficient of thermal conductivity with temperature, of some bricks at temperatures over 1,000° was suggestive of influences additional to the conduction of heat through the solid matter. Again, a calculation based on the fourth-power radiation law and data obtained from the determinations of thermal conductivity showed that the rate of heat transmission by radiation across the pore-spaces, at temperatures over 1,100°, may be, at least, comparable with the rate of conduction through the solid matter.

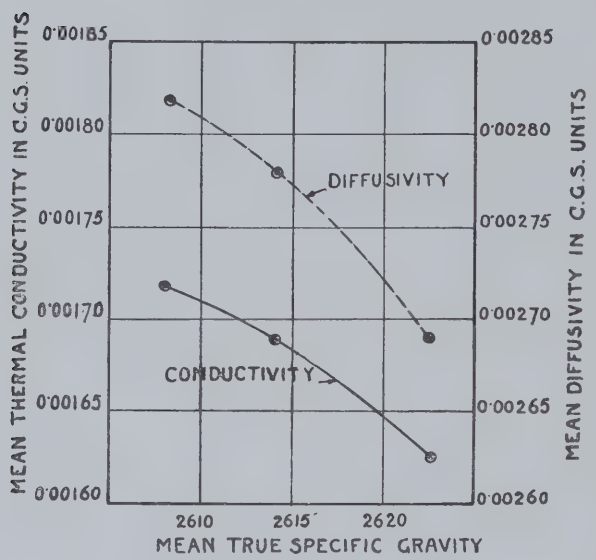


Fig. 6.

The emissivity of firebrick surfaces.

Using the more limited meaning of the term emissivity this physical constant may be defined as the ratio of the heat emitted from unit area of a specific surface to that emitted by an equal area of a "black body" or "full radiator" surface, when the temperatures of the two surfaces are identical. There are no published investigations in connection with the emissivity of refractory surfaces. In some work, at present unpublished, the present author obtained an increase in the value of the emissivity constant for a firebrick surface between 200° and 500°. The average value obtained for this range was 0.72. The value of this constant will vary considerably with the physical nature of the surface, and thus considerable variations are to be expected even with different samples of the same material.

THE DURABILITY OF SILICA AND FIRECLAY REFRACTORIES.

The durability of refractories in the circumstances of their special uses, is often limited by the influence of slags, slag-forming substances and impregnations, which they encounter. In fact, owing to the lack of understanding of the reactions involved in the phenomena of corrosion, erosion and disintegration, it is becoming increasingly difficult to specify products, which will withstand specific industrial conditions.

The corrosion of common refractories.

An analysis of the corrosion of refractories shows that, in the main, two factors are conspicuously concerned. The first depends on the surface reactions which occur between the corrosive agent, slag or dust, and the material of the refractory. The second is concerned with the penetration of the refractory by such agents, together with the physical disintegration, which follows such penetration, the former invariably accompanying the latter.

Chemical reaction takes place between " basic " and " acidic " materials in a very rapid manner ; for instance, at high temperatures, lime or ferrous iron will quickly react with silica forming a fusible silicate. Further, where an amphoteric oxide of the nature of alumina or ferric oxide, is present, reaction often occurs, resulting in the formation of " spinels." Thus, both silica and fireclay materials are prone to action in industrial use, where oxides are carried as dust, or slags are in contact with the refractory. The solution of the refractory by the slag at the areas of contact can proceed to saturation at a definite temperature, with the result that diffusion must take place before further solution can occur. If the slag is highly viscous this diffusion is hampered, with the result that the effect is merely superficial. The fluidity of the slag is thus of utmost importance in determining corrosive action. This factor depends on temperature and constitution. While in certain circumstances further solution may reduce the viscosity owing to such phenomena as eutectic formations, in other cases, the viscosity is increased. Thus the constitutional factor is interdependent with viscosity. With increase of temperature viscosity is usually decreased, with the consequent increase in the activity of the slag.

The penetration of the slag into the mass can take place either by way of the pores or by means of the solution of the matrix. In estimating the influence of porosity in this respect, the size and disposition of the pores must be taken into account. A measure of the penetrability is a far more helpful criterion than one giving the percentage porosity. According to A. Scott, " the mechanism of this type of corrosion resembles stoping; the corroding material penetrates certain pores, or it may be, cracks or crizzles on the surfaces of the refractory and works its way into the brick. Ultimately, particles of the latter, become surrounded by the corroding medium and tend to float into the slag, or become detached, as the case may be. In fireclay refractories, for example, grog particles may be detached in this way. Cracks on the surface of the brick are commonly responsible for the commencement of penetration in many cases, especially where the corroding agent is molten slag, as the latter is able to work its way by a crack, where it could not, by reason of its relatively high viscosity, penetrate the ordinary pore. If the material shows any tendency toward spalling, the latter will increase the amount of corrosion as the cracks formed during the spalling will serve as the ' loci ' for the penetration of the corrodant."

It has been, abundantly, proved that the matrix of a silica brick possesses very appreciable fluidity at the high temperature of its use, and tends to diffuse to cooler positions. This phenomenon considerably helps the passage of corroding agents such as iron compounds. How far the fluidity of the vitrified portion of a firebrick aids the passage of corrodants is a moot point, but the possibility cannot be lost sight of in the study of corrosion.

The influence of iron compounds.

Iron compounds play a conspicuous part in the failures of refractories, particularly in the carbonising and metallurgical industries. In gas-retort and coke-oven work the iron can pass from the coking coal to the brickwork. There is evidence which suggests that the mechanism of this passage is associated with the formation of a gaseous iron compound, which is decomposed on the surface or in the pores of the brickwork. Some suggest the formation of an iron carbonyl. While this is not refuted, the present author is of the opinion that steam exerts considerable influence both in the transfer and subsequent influence of iron. In vertical retort work, much evidence of the existence of newly deposited haematite is to be found.

Depending on the temperature and nature of the atmosphere the iron exerts a disintegrating or corrosive influence. Where the temperature is sufficiently high, fusible silicates will be formed, which depending on temperature gradient, porosity, and nature of matrix amongst other factors will tend to diffuse into the brickwork, probably causing ultimate failure. The nature of the atmosphere is of tremendous importance, a fact well illustrated by the work of A. E. J. Vickers. This investigator has shown that the influence of steam in reducing the refractoriness of a cone containing added ferric oxide is very pronounced, the reduction being of the order of 200° C., from 1,400°-1,200° in a special case. Further, such an atmosphere may reduce the temperature of formation of fusible iron silicates with the attendant increase in fluidity of such a slagging agent at the temperature of action. The atmosphere in gas retorts and coke-ovens is complex and variable, and such influences may be anticipated. Where " steaming " is adopted, the conditions certainly seem to be such as to render the formation of fusible iron silicates comparatively easy.

During scurfing, or the elimination of the incrustation encountered in the carbonising industries, portions of the refractory are sometimes dislodged from the retort. Although a number of explanations may be put forward to account for this trouble, it may be that the depositions on and in the wall may have a weakening effect, often at definite planes, which predisposes the material to failure during scurfing. It is not to be anticipated that a general explanation will be found to circumscribe this type of failure, variations with local circumstances being the rule. Local segregations of iron oxide are interesting in this respect. W. J. Rees, for instance, traced a case of " spalling " to the fact that these local segregations of iron oxide facilitate the decomposition of carbon monoxide with deposition of carbon. This, besides causing local adhesion of scurf, conceivably leads to a weakening of the silica material round the deposited carbon, with the gradual development or cracks. This instance, serves to emphasise that depositions and crystallisations taking place in the interior of carbonising walls give rise to a definite weakening of the structure of the refractory, with consequent ease of disintegration and spalling. The study of the physical chemistry and petrography of slags is very undeveloped. Such an avenue, fully prospected, is likely to be of the utmost value in elucidating the mysteries of corrosion and erosion.

The influence of iron-bearing compounds on the refractoriness-under-load of refractories is peculiar and variable. In general, the value of this property is considerably reduced for firebrick impregnated with ferruginous slag. In the case of silica products, however, many observers have noted that the absorption of slag, rich in iron, affects the softening point under load only to a relatively small degree. H. Sieurin, for instance, has shown that the presence of iron, estimated at 10 per cent. of ferric oxide, had a very small effect on the under-load value. Failure is, however, a matter of degree. Iron compounds impregnating a silica brick may have attacked or combined with the matrix, but the skeleton of silica in the form of tridymite and cristobalite may be unaffected. In these circumstances the product may possess definite structural stability. A point, however, must be reached when the strength of the silica skeleton will be reduced to a minimum, and failure will ensue. Thus it seems, that silica products have the ability to hold ferruginous slags for considerable periods without undue detriment to the structure. An under-load test on a " ferruginous " silica brick taken from a gas retort and containing an average of 8 per cent. iron oxide estimated as ferric oxide, demonstrated to the present author the squeezing out of a very fusible iron slag in the neighbourhood of 1,050°, but the test piece maintained its structural strength to a higher temperature than was normal for the unused product.

The influence of salty coals.

Coals used in the carbonising industries contain sodium chloride in amounts varying from a mere trace to approximately 0.5 per cent. When the coke has reached a temperature of 800°-900° the salt is volatilised and mixing with the gas in the retort or oven is decomposed with the formation of soda and hydrochloric acid. The soda fumes penetrate the brickwork and give rise to a series of actions detrimental to the brickwork. J. W. Cobb has shown that soda, alumina and silica can react together at 1,000° (but not at 800°) with the formation of sodium aluminium silicate, soda being formed by the hydrolysis or sodium chloride by steam. In a coke-oven wall a point is reached where penetration of the salt and the chemical reaction with the constituents of the fireclay may produce the sodium aluminium silicate, which has a low melting point. Ferric chloride which may be present in salty coal probably helps in the fluxing action by its reduction to ferrous chloride, steam being essential to this reaction. Thus, the drying of coal will probably result in a partial cure of the ills. Silica materials, by reason of their chemical purity, seem to be highly resistant to salt corrosion.

In connection with the influence of salt on the walls of a coke oven, the work of F. H. Clews and H. V. Thompson is interesting. The results obtained by varying the proportions of sodium chloride and silica indicate that the area of contact is more important than the composition of the mixture, unless the proportion of salt falls below 50 per cent. Although coke-oven temperatures are, comparatively, low, the action is prolonged month after month, so that drastic changes can be produced under conditions where the effects are inappreciable in ordinary laboratory experiments. According to W. T. Gardner, however,

" silica bricks are capable of absorbing alkali fumes over very considerable periods of time without disintegrations or loss of mechanical strength. Under similar temperature conditions the action of alkali fumes is sometimes more severe in the case of siliceous bricks than with silica. When one considers that the silica content of siliceous materials may be only approximately 5 per cent. lower than silica material, the difference in behaviour may at first sight appear to be somewhat extraordinary, but the higher alumina content (approximately 7 per cent.) of the former probably has an important bearing on the matter.

Temperature appears to play an important part in the attack of alkali fumes on siliceous material. At high working temperatures, an intermittent erosion due to detachment of a thin shaving of the face of the retort with the carbon at each scurfing period may take place. Under moderate temperature conditions, the alkali fumes appear to penetrate to a greater depth beneath the surface, before reaching a temperature sufficiently high to form a vitreous layer of silicate, consequently, disintegration may take the form of flaking off of an irregular layer, $\frac{1}{2}$ to $\frac{3}{4}$in. in thickness at intervals of 12 to 18 months.

Several years ago an investigation was carried out to ascertain the cause of the failure of some siliceous retorts, which had become unworkable due to roughness as the result of irregular erosion brought about by the use of salty coals. Analysis of the glassy surfaces layer revealed the fact that the alkali content had increased from 0.54 per cent. in the original bricks to 3.8 per cent. and the iron oxide (Fe_2O_3) from 1.50 per cent. to 2.8 per cent. The salt content of the coal in use was approximately 0.3 per cent.

In the case of fireclay material worked at low temperatures, alkali fumes cause the surface to become badly crazed after several years' working, but until disintegration takes place the crazing seldom causes any difficulties with the working of the retorts." In some retort settings, examined by the present author, silica products have been found to show the flaking trouble in a very accentuated form, so much so, that it does not seem correct to suggest that silica products are any more immune from flaking than the siliceous material.

Testing for resistance to slag corrosion and erosion.

The quantitative definition of those properties affecting the resistance of refractory materials to corrosion and erosion would find immediate application in the selection of these products. Such properties are but imperfectly understood and therefore at the present time, the tests, purporting to measure slag resistance, are generally considered very inadequate, and the results obtained by their use can only be interpreted on purely empirical lines. In fact, it seems that a number of tests are necessary to circumscribe the probable behaviour of a refractory when employed under conditions necessitating resistance to slags, dusts or other deteriorating influences.

To understand the physico-chemical disintegration of refractories is perhaps, more difficult because the conditions responsible are more complex. In many instances, the properties of the matrix are chiefly concerned. The factors chiefly requiring definition are (1) the nature and physical properties of matrix and its " strength " with respect to the resistance of internal strain, (2) the penetrability, (3) the cohesion between the grog and the matrix, (4) the influence of temperature and temperature variations on the physical properties of the matrix. Thus, the factors influencing spalling must, in great measure, influence the resistance of a refractory to physico-chemical disintegration.

SPECIAL REFRACTORIES.

At the present time, there are increasing endeavours to find industrial application for a number of special materials. In the main, the limitation of this application is the cost of the product, but instances are accumulating, where the initial outlay is outweighed entirely by the durability of the material in practice. The vogue of " sillimanite " is an illustration of this. Much of our knowledge concerning the industrial usage of special refractories is in the experimental stage, although in case of a number of material, commercial enterprise is all that is needed to foster their continued use.

A number of the special refractories are composite, in the sense that clay is used as a " bonding agent." In such circumstances, the properties of fired clay plays a conspicuous part in the durability of the fired product. Much of the information accumulated concerning the properties of clay and clay products finds a direct application in a consideration of the properties of these special refractories.

Sillimanite products.

There are a number of minerals composed essentially of aluminium silicates, which are found in varying quantities in different places, particularly including India and the United States of America. Sillimanite, cyanite, and andalusite are the more important from a commercial viewpoint. Sillimanite, the representative formula of which is $Al_2O_3.SiO_2$, is the most well known, although it should be mentioned that this name is sometimes used as a comprehensive term to include other prepared commercial aluminium silicates including andalusite and cyanite. Andalusite has a constitution which although similar to that of sillimanite, is structurally more complex. As with cyanite, however, the results of analyses of andalusite agree with the formula $Al_2O_3.SiO_2$. In making sillimanite products it is the practice to add about 20 per cent. of a plastic clay—usually ball clay—to act as a bond. The sillimanite is carefully graded, depending on the probable use of the product. It is essential that sillimanitic refractories receive very effective firings.

The properties of sillimanitic products have received more investigation with respect to the glass industry than any other. There seems to be a consensus of opinion that glass pots made from sillimanite possess superior properties. It has been suggested that they will show no pronounced resistance to corrosion by ferruginous slags. The laboratory properties are, however, highly satisfactory. Thus, the under-load behaviour is far superior to that of a fireclay brick, while the after-contraction is usually very low. Although there are definite recorded instances of the industrial spalling of the products, the laboratory tests circumscribing this property are quite satisfactory. In fact, sillimanite bonded with less than 20 per cent. clay, and fired so as to produce a mechanically strong product should be almost free from expansion differences between grog and matrix, and not sensitive to thermal shock, by reason of low and homogeneous thermal expansion of the composite mix. The properties of the bonding clay, however, determine, in no small measure, many of the laboratory and industrial properties of the final product.

Magnesite products.

These bricks find their major application in lining " basic " steel furnaces at the slag line for they are resistant to the corroding influence of calcareous slags. Raw magnesite, which is essentially magnesium carbonate and from which the bricks are manufactured, varies in constitution according to its origin. In this connection, it is interesting to note that in the main the Austrian mineral is much more impure than that mined in Greece, the preponderant impurity being iron oxide. This iron oxide seems to act very beneficially in manufacture, lending itself to the production of a more efficient product. Magnesite brick, being a " basic " refractory, find use where resistance to basic actions and slags are required. In the circumstances of this use, the chief fault encountered, is a spalling characteristic. The reversible thermal expansion of magnesite products is very large, being twice or thrice that of an average fireclay product. Such large expansions aggravate spalling, but they are not the basic cause of the phenomenon.

Carborundum products.

Carborundum, which is essentially silicon carbide, SiC, is manufactured by the interaction of sand and coke in an electric furnace at very high temperatures. It is an exceptionally hard crystalline substance, which contains between 70-64 per cent. of combined silicon, 30-26 per cent. of combined carbon, and small percentages of various impurities including free silicon, silica, iron, ferric oxide, aluminium, alumina. From the point of view of refractories, carborundum products can be divided into two groupings—the one being almost entirely crystalline commercial carborundum, the other commercial carborundum bonded with additions, chiefly clay. The former class contains upwards of 93 per cent. of silicon carbide and these products are subjected to such a kiln firing as will produce a continuous crystalline structure. They are known commercially as " refrax " or " crystalon." Providing recrystallisation during kiln firing is satisfactorily developed, mechanical strength under tension or shear is high, and " refrax " or " crystalon " possess specially high resistances to spalling.

In general carborundum is highly resistant to chemical action. Its use in certain industrial furnaces, however, appears to be hampered by changes in its constitution, which take place during continuous use. In the circumstances of industrial high-temperature practice, the conditions of use of carborundum must be very carefully defined.

The thermal expansion of silicon carbide is very low. Further, this data suggests that carborundum is free from inversion of the α-β type. Consequently, well-fired " refrax " or " crystalon " should be very resistant to spalling. The thermal conductivity of this product is comparatively very high, being at least five times greater than that of firebrick. S. Wologdine gave 0.023 C.G.S. units for the coefficient of thermal conductivity of carborundum at 1,000°, when that of a fireclay product is given as 0.0042, and that of a silica product 0.0020 at the same temperature. It appears that the specific heat of carborundum reaches a maximum in the neighbourhood of 500° and is very low at 1,000° C., consequently the heat capacity at high temperatures is small. These superior thermal properties are a definite advantage in the use of the product for such purposes as muffle walls, when the constitution can be maintained unimpaired. At high temperatures carborundum is structurally a strong material, for it withstands the conjoint influences of pressure and temperature exceedingly well. Its refractoriness and refractoriness-under-load values are very high.

For many industrial applications, clay-bonded carborundum shapes or " carbofrax " seem preferable in many respects to " refrax." In the first place, the price may be considerably less owing to the reduction in the quantity of silicon carbide and the less severe firing procedure necessary. Again, it is quite possible that a suitable vitrified bond will act as a protection against " oxidation " of the carborundum grog, which occurs at moderate temperatures. Thirdly, so far as available data go, the use of a clay bond, suitable in quantity and nature confers high tensile strength and hence other things being equal, a better resistance to thermal shock.

The object of this contribution has been to indicate the industrial significance of refractory materials technology. In so short a space, many important facts and themes have either been omitted or treated very generally. Thus, a study of the literature indicated in the references will materially supplement this article.

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Chapter 3.

THE THERMAL INSULATION OF FURNACES AND KILNS.

By A. E. Hubbard, Assoc. Met.

Within the last few years, the question of thermal insulation, as applied to furnace and other structures in which a high temperature is generated, has received serious consideration, yet the magnitude of the fuel-saving which can be effected by its means has not been properly appreciated by many users, by whom the subsidiary economies and advantages which accrue have also not been considered.

The importance of lagging steam lines has, of course, been appreciated for some time, and attempts have been made, in certain of the older types of high-temperature equipment, such as firebrick kilns, etc., to conserve heat by building very thick walls. This practice, as will be shown later, in the section dealing with kilns, defeats, to a great extent, its own object.

The table given below, compiled from various sources, shows how important an item radiation is in the thermal balance sheet of various typical furnaces.

TABLE I.—HEAT BALANCES OF TYPICAL HIGH-TEMPERATURE EQUIPMENT.

Type of Equipment.	Heat lost in Radiation.	Heat lost in Flue gases.	Heat carried out in product.	Heat absorbed in product.	Other losses.	Reference. By	Reference. In
Rectangular Ceramic Up Draught Kiln	71.1%	18.6%	6.7%		4.58%	A. V. Bleininger	Trans. Am. Ceram. Soc. Vol. 1
Open Hearth Furnace.....	60.8%	13.6%	15.9%		9.1%	J. W. Richards	Metallurgical Calculations
Down Draught Kiln. 26ft.....	54.9%	29.9%	—	11.3%	3.9%	A. V. Bleininger	Trans. Am. Ceram. Soc. Vol. 1
Down Draught Kiln. 28ft.....	49.51%	27.33%	—	19.55%	3.51%	A. V. Bleininger	Trans. Am. Ceram. Soc. Vol. 1
Reverberatory Furnace	47.0%	40.0%	7.0%	6.0%	—	H. O. Hofman	General Metallurgy
Continuous Tunnel Kiln	45.0%	35.83%	17.27%		3.27%	C. B. Harrop	Trans. Am. Ceram. Soc. Vol. XX.
Reverberatory Furnace	39.5%	45.7%	0.5%	3.6%	10.7%	J. W. Richards	Metallurgical Calculations
Down Draught Kiln. 30ft. (Producer Gas Fired)	34.9%	28.8%	20.6%	2.2%	13.5%	C. B. Harrop	Jour. Am. Ceram. Soc. Vol. 1
Lead Roaster	25%	22%	23%	22%	8%	J. W. Richards	Metallurgical Calculations
Rotary Cement Kiln	20%	35%	20%	25%	—	Taylor	Trans. Am. Inst. Chem. Vol. X.
Lime Kiln	17%	22%	11%	39%	12%	R. K. Meade	Jour. Ind. Eng. Chem. Vol. 13 No. 3.

By the use of suitable insulating materials, radiation-losses can, in most cases, be reduced by 75 per cent.; the chief exception being melting furnaces where, at the present time, the use of insulation has to be limited to regenerators or recuperators, uptakes and gas-mains, owing to the fact that the operating temperatures are too near to the limit of refractoriness of the lining bricks to permit of the insulation of crowns and side-walls.

When a high temperature is generated in a furnace, heat flows by conduction through the walls to the outer surface, from whence it is dissipated to the atmosphere or surrounding bodies by radiation, and the amount of heat conducted must be equal to that dissipated, and vice versa, thus, the factors which govern the flow of heat by each by the three methods of propagation—conduction, radiation and convection—are all operative in affecting the heat losses from a furnace or similar structure.

Conduction.

The mathematical theory of the flow of heat by conduction is due mainly to the work of Fourier (Theorie Analytique de la Chaleur), the parallel flow of heat in the steady state being expressed as:—

$$Q = k \frac{\theta_1 - \theta_2}{x} A t$$

where, Q=quantity of heat conducted in unit time.

θ_1 and θ_2=temperatures of isothermal planes.

A=Area of planes.

x=Distance apart of planes.

k=Thermal conductivity of the material ; it varies with the temperature.*

Thus the flow of heat, by conduction, through unit area and thickness of a given material in unit time, is governed by the difference between the temperature of the two surfaces considered.

A further controlling factor is the effect of the surface film, the actual temperature gradient from furnace atmosphere to outside atmosphere being represented, diagrammatically, in Figure 1, where A represents the furnace temperature; B the hot surface temperature; C the cool surface temperature; and D the atmospheric temperature.

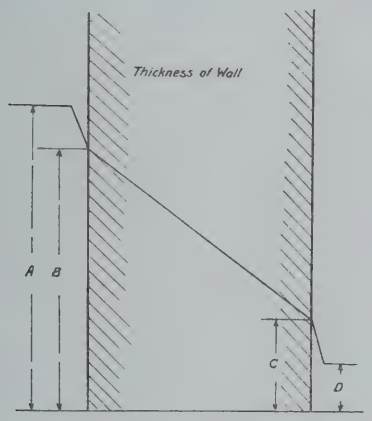


FIG. 1.

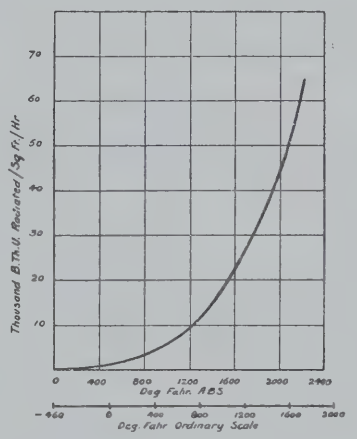


FIG. 2.

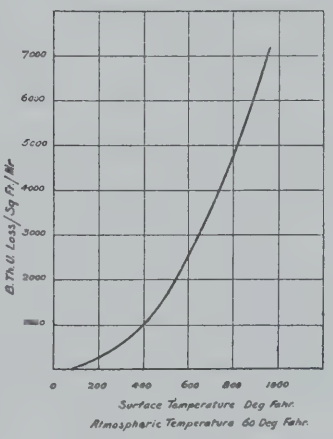


FIG. 3.

Radiation.

The law governing the passage of heat by radiation is that propounded by Stefan, and modified by Boltzmann, who showed that, from thermo-dynamic considerations, the fourth power law only held for " black body " conditions, a " black body " being one which absorbed all the energy falling upon it, reflecting none, e.g., a body in a uniformly heated structure viewed through a very small aperture.

The variation of the absolute radiation with temperature, according to Stefan, is illustrated in Fig. 2, which has been adapted from Dalby's Report on Heat Transmission (Proc. Inst. Mech. Eng., 1909, Parts 3 and 4).

Convection.

This factor has been studied carefully in its bearing on steam boilers, but there is very little published data on its relation to the loss of heat from furnace walls, although it is undoubtedly an important factor. The two main types of losses by convection are those due to (i.) natural convection, and (ii.) to forced convection. In natural convection, the currents set up are those due to the difference in density caused by the heat from the body itself, i.e., those occurring within a closed air-space, whilst in forced convection the air is in motion due to external causes, *e.g.*, draught, and the movement due to natural causes becomes almost negligible. The latter case is, obviously, the one which applies in ordinary furnace work.

*" The Mathematical Theory of Heat Conduction," Ingersoll & Zobel. Pub. Ginn & Co., London.

The magnitude of the heat carried away from a surface by convection is governed by the physical properties of the air, such as viscosity, density, specific gravity, etc., as well as by the geometrical shape of the surface, and as the mathematics of the subject is particularly involved, experimental determinations have had to be made.

Experiments by Griffiths and Davis (Special Report No. 9, Food Investigation Board D.S.I.R.) showed that, at low temperatures, and with temperature differences up to 100° C., the heat-loss by convection increases as the 5/4 power of the excess temperature under conditions of natural convection; they also showed that the convection-losses from a horizontal surface facing downwards were about 30% less, and those from a horizontal surface facing upwards about 25% greater, than the losses from a vertical surface. These proportions are, of course, modified under conditions of forced convection, and, it is under such conditions that future investigations should be conducted, since there are several empirical methods of calculating approximate heat-losses from furnace-structures, all of which assume still air conditions. A very useful graphical method is that described in a paper by Hadfield and Sarjant (Journ. Iron and Steel Inst., 1919, II., p. 68). The results obtained by this and other methods, whilst being comparable amongst themselves, and, therefore, of value in determining the efficiency of various insulating materials, do not correspond with the results obtained by experiment, the actual heat-loss being greater than the calculated loss owing to the fact that the empirical formulae do not take forced convection into consideration.

The total quantity of heat transmitted, per unit area, in unit time, under still air conditions from rough vertical plane surfaces, can be calculated from the formula—

$$*I=.155\left[\left(\frac{T_0+460}{100}\right)^4-\left(\frac{T_a+460}{100}\right)^4\right]+.25\,(T_0-T_a)^{5/4}$$

Where I $=$B.Th.U. emitted per sq. ft. per hr.
T_0 $=$Surface temp. °F.
T_a $=$Temp. of surrounding air °F. (assumed to be still).

The results so obtained are plotted in Fig. 3, but the actual heat-loss obtained in practice would, as has already been pointed out, be somewhat higher, owing to the effect of draughts.

Reference to Fig. 3 will show that, for a surface temperature of 400° F., there is a heat loss of 1,000 B.Th.U./sq. ft./hr., whilst the heat-loss, with a surface temperature of 200° F., is only 250 B.Th.U./sq. ft. The use of an efficient insulating material will produce, in some cases, an even greater lowering of surface temperature than this, but even in this instance, the saving in terms of coal with a calorific power of 12,000 B.Th.U. would be 4 cwt. per sq. ft. of radiating surface, per year.

For many years, it has been thought that an air-space built into the walls of a furnace structure was a good insulator, the fallacy having arisen from the fact that the data published on the thermal conductivity of air, shows it to have an extremely low conductivity, 0.000055 cals/cm/cm^2 thickness/sec/°C., or, 0.16 B.Th.U./sq. ft./inch thickness/hour/°F. This figure only obtains however for an ideal air space, i.e., one in which radiation and convection are eliminated. The significance of the qualifying conditions would appear to have been overlooked, despite the fact that, in 1908 Nusselt showed that with a hot face, at 247° C. the efficiency of an air space was, only, 40% of that of a similar space filled with infusorial earth.

In 1912, Ray and Kreisinger (The Flow of Heat through Furnace Walls, U.S. Bureau of Mines, Bull. 8) carried out an extensive investigation into the subject, using a tunnel furnace, 35ft. 6ins. by 3ft. by 3ft. 3in. high, operating at about 2,000° F. (1,100° C.), and having a 2-in. air space built into the walls. They found that the temperature-drop, across the air-space, per unit thickness was considerably lower than the drop across the same thickness of firebrick and that when the hot face temperature exceeds 227° C. (440° F.), ordinary firebrick is a better insulator than is an air-space. This being the case, it is obvious that the introduction of baffles into an air-space, would tend to break up the convection currents, and that the division of the air space into small cells, would still further increase its resistance to the passage of heat. The baffles, or cell walls, must, of course, be made of material of sufficiently low thermal conductivity.

*Trinks : " Industrial Furnaces," Vol. I., p. 64.

Thus, a highly porous material ought to be an efficient insulator, though the question of the size and shape of the pores is of primary importance. It is essential that, the pores be minute and isolated from each other, and, therefore, the volume-porosity of the mass cannot be taken as a measure of the insulating efficiency of a material. Some substances with a porosity of 85—90 per cent. have been proved to be inferior insulators to others with a porosity of 75—80 per cent., the reason being that, in the former the pores are large and are interconnected. Mellor has shown that the quantity of heat radiated across a pore space 0.5 cm. dia. at 730° C., is equal to that which would have passed by conduction through the solid, at the same temperature, whereas, for a pore space of 0.1 cm., the radiation does not equal the conduction until the temperature is 1,400° C.

Considering insulating materials from the point of view of practical application, we have, as a primary requirement, a high percentage of minute, disconnected pores. It is necessary, also, that the mechanical strength of the material is such, that it will withstand handling without breakage and it must have a reasonably high crushing strength, for, although, in a cold furnace the load to be borne by the insulating material is small (being, as a rule, no more than the weight of a column of itself, equal to the height of the wall), various complex stresses are set up when the furnace is heated, which may operate on the insulation in a degree dependent on the design of the furnace. An insulating brick made of high-grade infusorial earth, will have a crushing strength of 400 lbs. per sq. inch, which will be found to give an ample factor of safety for all purposes for which such a brick can be used.

Refractoriness.

The refractoriness of insulators is important for, although, in most cases, the insulating material is placed between the refractory lining and the outer casing of the furnace, the outer surface of the refractory lining is at a much higher temperature, when backed by insulation, than it is when backed by red bricks or plates. This condition renders unsuitable for furnace work, such materials as the various organic porous materials (cork board, etc.), which are used for insulation at low temperatures, also, materials such as slag-wool, asbestos, and porous materials with a gypsum base the insulating power of which breaks down at comparatively low temperatures, due either to a physical or a chemical change taking place.

The material from which most of the insulators suitable for use under furnace conditions are made is diatomaceous or infusorial earth. This term covers a very wide range of material found in deposits in various parts of the world, consisting of an aggregation of the minute siliceous skeletons of minute organisms which, themselves, consist simply of a number of cells. In a sample from one particularly pure deposit the number of cells, per cubic inch, is of the order of 50×106, so that the radiation and convection factors, in such a material, when used as an insulator, will be negligible. In the subsequent consolidation of most of these various deposits infiltration of argillaceous, calcareous and ferruginous material has taken place with the result that clayey impurities are found varying from 5 per cent. in the best samples up to as much as 20 per cent. in the worst commercial samples, and this so governs the refractoriness and thermal conductivity of the material, that, so far as the writer is aware, there is only one deposit, namely, in California, which is of a degree of purity sufficiently high to permit of its use direct as an insulator. This material is cut from the rock in blocks, the size of standard bricks, and forms a very efficient insulator for high-temperature work.

In order to use some of the more impure forms of diatomaceous earth, they are ground up with sawdust or other finely granular organic material, moulded into brick form and burned, the organic material burning away and leaving comparatively large pores which are interconnected, since the products of combustion of the organic material have to find a way out of the mass. It is obvious that a siliceous material containing, say, 10 per cent. of clayey impurities will have a lower refractoriness than one containing only 5 per cent. of the same impurities, and it should be borne in mind that the " burning " of a clay or semi-silica product is what has been described by Mellor as an arrested reaction, i.e., further contraction will take place if the material is re-burned to a higher temperature, or, is maintained for a considerable period at a temperature near the burning temperature. The average burning temperature of those diatomaceous earth insulators, which have been rendered artificially porous, by the addition of organic materials, is in the

region of 900° to 1,000° C., but, on keeping a sample of such a brick recently at 800° C. for two hours, the writer found that a contraction of 27 per cent. of the original length occurred. This large contraction may be abormal, but it illustrates the necessity for selecting only the highest grade of material for use as insulators in high-temperature work, for, if contraction occurs when the brick is built into a furnace wall, small flues will be formed which will lead to a great loss of heat.

Various attempts have been made to produce insulating bricks by mixing a large proportion of sawdust, or other organic material with fireclay, the material being moulded into brick form and subsequently burned at about 900—1000° C.*; the product has, however, little to commend its application since the pores are, comparatively, large and are interconnected. Thus, the thermal conductivity,† whilst being fairly low at temperatures up to 200—300° C., increases very rapidly at higher temperatures. Moreover, on account of the burning temperature being kept as low as possible to maintain the maximum porosity and so reduce the conductivity, the mechanical strength is low.

From what has been said, it will be realised that the most satisfactory insulating material for high-temperature work, is that made from the purer types of diatomaceous earth, in which the porosity is due, solely, to the air-cells in the siliceous skeletons, and has not been produced by the burning out of organic material, or by other artificial means.

In selecting an insulating material for use at high temperatures, particular attention should be paid to its mechanical strength and to its conductivity over a range of at least 800° C., as the highest efficiency is only obtained by the use of materials which, throughout that range, maintain a very low rate of increase of thermal conductivity with temperature. The maximum increase in conductivity over such a range, should not exceed 15—20 per cent. of the conductivity at atmospheric temperature.

Effect of insulation.

With regard to the effect of insulation on the refractory lining, very little data has, as yet, been published, and some reluctance has been shown in the adoption of insulation, for fear lest it might have an adverse effect on the refractory material. This has arisen from the fact that instances have occurred, where insulation has been applied to high-temperature furnaces without any consideration having been given to the conditions under which the refractory material is used. Thus, in one instance, the crown of an open-hearth furnace was insulated with disastrous results, as the crown collapsed from being overheated, because after insulation, the heat could not escape, as before. Yet even though insulation, in such a case, did cause failure of the crown it is unwise to condemn the practice of insulation as a whole. The temperature and other conditions in an open hearth furnace, working at say 1,750° C., are such that only the highest grade of silica brick will stand, and then only if the upper surface of the bricks is exposed, so that a large quantity of heat can be dissipated. In general what happens under such conditions, is that, when a new 9-in. crown is put in, the first two or three inches burn away fairly rapidly, leaving a thin roof through which sufficient heat can escape to keep the remainder of the brick reasonably rigid. Now, if a course of insulation were to be put on such a crown and the escape of heat reduced, the mean temperature of the brick would be raised, very considerably, with the result that the roof would rapidly burn out. A. J. Dale has shown that the behaviour of a refractory material under load is, to some extent, independent of its absolute refractoriness as measured by the usual squatting test. Many factors appear to control the softening range of a firebrick, which render the routine determination of that important property somewhat difficult. It may be taken, however, in general, that no softening under normal industrial loads will occur at temperatures below 1,300° C., and, in the case of certain high-grade firebricks, the softening range does not commence until 1,400° C. is reached.

In deciding whether or not insulation can be applied to a high-temperature furnace, the softening range of the firebricks used as a lining, is, in most cases, the governing factor. The refractoriness of the insulating bricks need not be nearly so high and such bricks of ample refractoriness can be obtained.

*Wologdine (Bull. Soc. d'Encour. †P.879, 1919) having shewn that under-burned clay products have a much lower conductivity than well-burned material.

There are, at the present time, insulating bricks on the market which have a thermal conductivity as low as 0.00076—0.00138 C. G.S. units, when exposed to a temperature of 1,350 to 1,500° C. If, therefore, high-grade firebricks are used, no trouble will arise from the insulation of a furnace, operating at, say, 1,500° C., because the mean temperature of the firebricks will certainly not exceed 1,400° C., and the advantage, both as regards fuel economy and ease of temperature control, will show an adequate return on the outlay involved in using the highest grade both of refractory and insulating materials. For those parts of furnaces which are at a higher temperature, the insulation is much more difficult to arrange satisfactorily.

The use of high-grade refractory materials has not received sufficient consideration by many users some of whom prefer to use the cheapest possible grade that will serve their purpose, irrespective of the cost involved by frequent repairs and re-linings, whereas the use, in the first place, of high-grade refractory firebricks costing say £3 per 1,000 more than the cheaper ones, would rapidly pay for themselves. This is particularly important in an insulated furnace, for in it the temperature gradient, through the refractory material is very much less steep than in an uninsulated wall and, consequently, the strain imposed on the bricks is considerably less as they are made less sensitive to temperature changes.

There is a great advantage to be gained by the use of powdered diatomaceous earth, as a covering for the crowns of annealing furnaces and of some reheating furnaces and kilns in place of sand, which is, at present, commonly used. The thermal conductivity of sand is fairly close to that of firebrick, and, may, for the purpose of comparison, be taken as 10 B.Th.U. per sq. ft./hour/°F./1in. thickness, while the weight of sand is about 120 lbs. per cu. ft. A 4-in. layer of sand, laid over a 9-in. crown, will place a load of 40 lbs. per sq. ft. on the crown and will, assuming the furnace to be operating at 1,000° C., reduce the heat losses by, approximately, 160 B.Th.U. per sq. ft., or 17.5 per cent. of the loss from a bare 9-in. crown. A layer 4in. thick of diatomaceous earth, packed to a density of 14 lbs. per cu. ft., will reduce the heat losses by 780 B.Th.U. per sq. ft., or 75.5 per cent. of the loss of the bare crown, and with a load of less than 5 lbs. per sq. ft. on the crown.

Advantages of insulation.

Before considering the applications of insulation to the various furnaces and allied structures, it may be well to outline, briefly, the various advantages which are to be obtained by it. These are: (*a*) a large reduction in the amount of heat lost by radiation; (*b*) an easier maintenance of a uniform temperature in the furnace, kiln or allied structure; (*c*) greater durability of the refractory materials and of the interior generally of the structure, except in the few cases where insulation is undesirable; (*d*) a great saving in fuel resulting from the foregoing economies; (*e*) an important effect on shut-down losses, the rate of cooling the furnace being so retarded that the temperature-drop, overnight, rarely exceeds one-third of that in an uninsulated furnace; similarly, with regard to week-end losses: instead of having to light up the furnace on Sunday morning, in order to have it at working heat on Monday, it does not require lighting before Sunday night, or even, in some cases, early Monday morning, thus effecting a considerable saving both in fuel and labour, and (*f*) considerable improvement in working conditions, around the furnace, which, though difficult to convert into terms of fuel, is shown by the improved efficiency of the men.

To illustrate many of the advantages of insulation, the annealing process may be considered, since it is used in some form in many industries. Broadly speaking, this process consists of raising materials or articles to a definite temperature, maintaining them at that temperature, and then cooling at a definite rate, depending on the materials or articles being treated.

The efficiency of the process varies inversely as the quantity of fuel required to anneal a given quantity of "stock." In the usual type of furnace, at least 25 per cent. of the fuel consumed is utilised simply to make good the heat-losses through the structure, and if a course of, say, 4½ins. of efficient insulating material is included in the walls, crown, doors and base, these heat-losses will be reduced by 60-75 per cent., and, thus, the fuel required to make good loss of heat by radiation will be only 6 to 10 per cent. of the original fuel consumption. Experience has shown that the value of the fuel, so saved in the first year of operation, is far more than the cost of insulation; furthermore, when the process permits, the furnace can be brought up to the required temperature more rapidly and is very much more sensitive

to control. In a well-insulated annealing furnace, an even temperature can be maintained throughout, even up to the doors, as a result of which, it is often possible to pass more articles through the furnace in a given time and so increase the output.

Taking as an example, a typical annealing furnace, as shown in Fig. 4, the inclusion of a $4\frac{1}{2}$in. course of insulating brick, between the refractory lining and the red brick casing, calls for no alteration in design, it being often possible to substitute the $4\frac{1}{2}$in. of insulation for $4\frac{1}{2}$in. of second-grade firebrick. In the base, a mat of insulating concrete should be laid upon the concrete foundation, this material having sufficient mechanical strength to replace an equivalent thickness of ordinary concrete, without in any way reducing the stability of the structure. The importance of base insulation is not generally realised, even amongst those who appreciate the advantage of side-wall and crown insulation, although, in some instances, trouble has been caused by the firing of the surrounding ground, owing to the passage of heat through a furnace base. This particularly applies to " made " ground, where the cinders, etc., composing it, may contain a fairly high proportion of unconsumed carbon. In other cases, where furnaces have been built on wet clayey ground, there has been a constant " drag " on the furnace, due to the continual evaporation of water

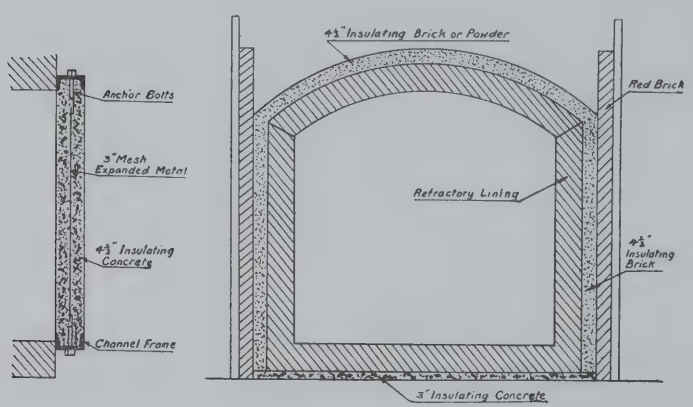


FIG. 4.—*Section of Typical Insulated Furnace.*

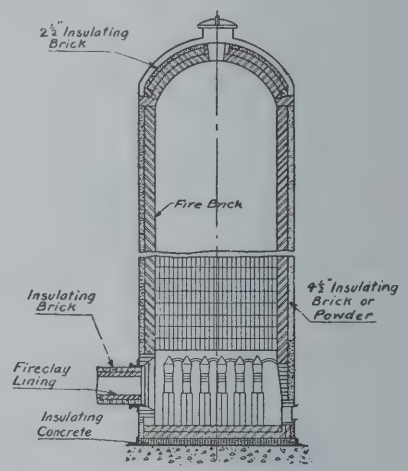


FIG. 5.—*Method of Insulating Hot Blast Stove.*

in the foundations, or the heat, passing away to the ground, has baked the clay, causing it to contract and crack, and leading to the eventual collapse of the furnace. Again, in some works where the water-level is very near the surface, much inconvenience has been caused because of the impracticability of building a furnace in a certain place, but by the use of a heavily insulated base the water trouble can, in some cases, be overcome. Another very useful application of insulating concrete lies in the manufacture of monolithic doors, the use of which overcomes many of the troubles inherent to brick doors, and at the same time considerably reduces the heat-loss through the doors. As a rule, the door is the thinnest part of a furnace structure, and, consequently, the heat-losses are greatest at that place.

The application of insulation in the annealing process has been dealt with at length, because it is one which is used in a wide range of industries, and what has been said in regard to it, applies equally well to various other heat-treatment processes.

Iron and steel industry.

The main applications of insulation to a blast-furnace plant are in the hot-blast stoves, mains and bustle-pipes or horseshoe-bends, also in the downcomers, dust-catchers and hot-gas mains to the stoves, boilers, etc., where the gas is used direct, or where it is cleaned whilst hot. Fig. 5 shows a method of insulating a hot-blast stove, insulating bricks or powder being equally suitable. In an iron smelting plant, recently constructed in this country, $2\frac{1}{2}$ ins. of insulating brick was built behind the firebrick lining, and the space between the insulating bricks and the shell (averaging about 2ins.), was filled with powder. This

method of construction is very serviceable, provided a powder is used which will not settle, as it acts as a buffer course between the lining and the shell. If, on the other hand, a powder which settles or a brick which is mechanically weak is used, the repeated expansion and contraction of the lining will tend to grind down the insulation, leaving an air space in the upper part of the stove, and giving a dense mass in the lower part. This almost invariably occurs when sand or ashes are used and leads, eventually, to the cracking of the shell plates.

In the various papers which have been published, dealing with the heat-balance of hot-blast stoves, the radiation-loss has always been assumed to be 10 per cent. of the total fuel consumption or it has been taken by difference, and it would be a difficult matter to calculate, accurately, these losses, owing to the many variables which operate. That the loss of heat is serious may be proved by observing the cloud of steam which rises from a battery of stoves on a wet day. With insulated stoves much of this loss of heat is avoided and, in addition, a more regular working of the furnace can be obtained. The fall in temperature for a given period " on blast " is considerably less than in an uninsulated stove, under similar conditions, and since the heat-requirement of the stove is less, a considerable volume of gas is rendered available for other purposes.

In the hot-blast and gas-mains, the primary importance lies in the fact that the drop in temperature between stoves and furnace is very considerably reduced but, in designing new plant, the additional advantage exists that the weight of the main is reduced, since the usual 9ins. firebrick-lining weighing 120 lbs. per cu. ft. is replaced by a lining, consisting of 6ins. firebrick, and 3ins. of insulating brick, weighing only 30 lbs. per cu. ft.

Open-hearth furnaces.

In the steel industry, the insulation of the crowns and parts of the sides of open-hearth furnaces is, as has already been pointed out, not yet practicable, but the insulation of the regenerator-chambers (side walls, base and arches), uptakes, slag-pockets and gas-mains, is well worth consideration. Clements (Journ. Iron and Steel Inst., 1922, i., p. 433) gives the radiation loss from the regenerator as 15.5 per cent. of the total heat supplied to the furnace, and the loss from the flues as 4.1 per cent. He also states that, by the use of suitable insulating material, it should be possible to prevent the whole of this radiation loss. In practice, it is not found to be possible to effect a reduction of much more than 75 per cent., but the great value of such a reduction has been proved in many American open-hearth plants, where insulated furnaces have been in operation for several years. One plant has reported a saving of 7 gallons of oil per ton of steel melted, and, in another plant, by the rebuilding and insulating of regenerators and uptakes, a saving of 18 gallons of oil per ton of steel was obtained, half of which saving was credited by the plant manager to insulation. In the absence of data as to the exact kind of oil used, it may be safely be assumed that the saving is equivalent to $1\frac{1}{2}$ cwts. of coal, per ton. In another instance, it was shown that insulation enabled a furnace to be brought up to working heat from cold in 3 days, as against 6 to 8 days before insulation, and the regenerator-temperature was raised from 1,800° F. to 2,600° F. In other cases, reductions in melting times of 40 to 70 minutes have been obtained.

When waste-heat boilers are coupled up to the furnaces, insulation becomes even more important. Dyrssen (Journ. Iron and Steel Inst., 1924, i., 183) has shown that, by the insulation of the regenerator chambers and flues, and by the reduction of air-infiltration, the steam output can be raised to correspond to about 34 per cent. of the heat in the fuel; also that the effect of insulating the downtakes is to deliver the products of combustion to the regenerators at least 200° F. hotter. The importance of the elimination of air-infiltration is well known. Dyrssen states that it may amount to more than 100 per cent. of the weight of waste gases at the port ends, and it may be pointed out that, with suitable insulation, the external surface-temperature of the regenerators can be reduced to such an extent as to permit of the use of a plastic air-proofing material.

The necessity for the insulation of mixers, hot metal cars, and soaking pits, is obvious, but, owing to the high temperatures attained, only refractory and insulating materials of the highest grade should be used.

Gas-producers and gas-mains.

In building gas-producers, it is a common practice to fill the annular space between the lining and the shell with sand or ashes, which form a layer of material with a thermal conductivity very little lower than that of firebrick. This mass after a comparatively short time, tends to settle, leaving an air-space in the upper part, and giving a dense mass in the lower part, which may eventually lead to the cracking of the plates. In other cases, slag-wool has been used, but this suffers from the same defect; its insulating value is derived from the air-space between the siliceous fibres, and, when these fibres are broken down by the "breathing" of the lining, a solid, sandy mass in the lower part of the annular space is formed. Trouble has, also, been experienced from the corrosive effect of this material on the plates with which it comes into contact, the corrosion being due, possibly, to the sulphur present in the slag. The use of certain types of diatomaceous earth eliminates the risk of such troubles, as this material is chemically inert, and it has been proved by experience that no settling takes place; moreover, the thermal conductivity of such a material is only about 0.35—0.4 B.Th.U. per sq. ft. as against 10 B.Th.U. for sand.

The insulation of gas-mains used for hot gases, is a source of considerable fuel-economy. In tests recently carried out by F. Ellis it was found that the reduction in heat-loss in a gas-main 5ft. diameter with a 4½in. firebrick lining, when insulated with a material having a thermal conductivity of 0.67 B.Th.U. per sq. ft., was equivalent to 2,800 lbs. of coal per year per foot of main. It will readily be realised what an economy could be effected by this means in the average steel works. In addition to the fuel saved by the reduction of radiation losses from the main, much hotter gas is delivered to the furnace, and this produces a further reduction in fuel-consumption, and at the same time the tarry material usually deposited in the mains is, to a great extent, carried through to the furnace, giving a richer gas and lengthening the periods between successive cleanings of the main.

Glass industry.

A number of papers have been published recently, dealing with the insulation of the tank-furnaces used in the manufacture of glass, and, whilst the figures given for radiation-losses are not strictly comparable amongst themselves, they appear to lie between 50 and 70 per cent. of the heat supplied to the furnace. McSwiney (Glass Industry, Vol. 6, 1925, pp. 139 and 161) states that the quantity of coal required to maintain a 20ft. by 40ft. tank, at glass-melting temperature, when no glass is being melted, is 25 tons per day, whilst the heat required to bring a ton of soda-lime-batch up to melting temperature (2,450-2,550° F.), and to convert the batch-ingredients into glass is, under average conditions, rather less than that which can be supplied by two cwts. of coal.

There has been a considerable amount of controversy in the past, as to the effect of insulating such tanks, but results are rapidly showing that this is feasible. In one case, a crown insulated with 5ins. of a high grade of diatomaceous earth showed a considerable fuel-saving without causing any undue signs of deterioration in the refractory material. In another instance, insulation of the base and side walls led to a reduction of 12 hours in the melting time, and, it is further claimed that the whole body of glass is kept in the molten state, as opposed to the usual conditions where only the upper part is fluid. Experiments have shown that in an uninsulated tank there is a drop of, approximately, 100° F. for each foot below glass level (see Fig. 7). Owing to the greater mobility of the body of the glass a completely insulated tank it is found to be possible to run the latter at a rather lower temperature and still maintain the proper output. Such a practice increases the durability of the refractory material of which the tank is built. Insulation also tends towards the elimination of cordy glass and the vertical erosion of the tank blocks, on account of the increased uniformity in the temperature throughout the glass.

The effect of insulating the regenerators and uptakes, is similar to what has been said under the heading of open-hearth regenerators. By such insulation, a fuel-economy of, at least, 17 per cent. can be secured. Fig. 6 shows the type of insulation suitable for the regenerators and uptakes in a glass-furnace.

The insulation of lehrs also enables an important fuel-economy to be effected. It has recently been shown (The Economics of the Annealing Process, E. A. Coad Pryor, Soc. Glass Tech., 1926), that by the use of suitable insulation, a lehr can be constructed in which glass can be satisfactorily annealed without the use of external heat. Insulation can be applied to existing lehrs, etc., as a veneer course applied to

the side walls and crown, and will considerably reduce the fuel-consumption. The same practice may be adopted for the nose of a tank furnace, as well as in the regenerator chambers and uptakes.

An interesting use has recently been made of insulating concrete in the construction of a door to cover the opening in the tank out of which a machine draws glass at a large lamp works. When this door was used, the fall in temperature over the week-end was not sufficient to chill the glass, with the result that 15 minutes after starting up on Monday perfect bulbs were being produced, whilst, previously, nearly half a day was occupied before the glass attained the correct temperature.

Ceramic industry.

In the various branches of the ceramic or clayworking industries, perhaps, more than in any other, the conservation of heat has been neglected, the heat-losses from an ordinary, round down-draught oven or kiln being 30 to 60 per cent. of the heat supplied, some attempts have been made to reduce heat-losses

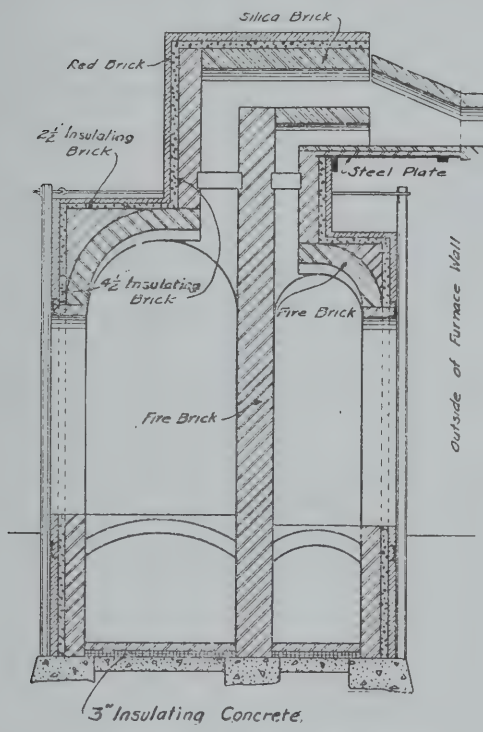


FIG. 6.—*Insulation of Glass Furnace Regenerators.*

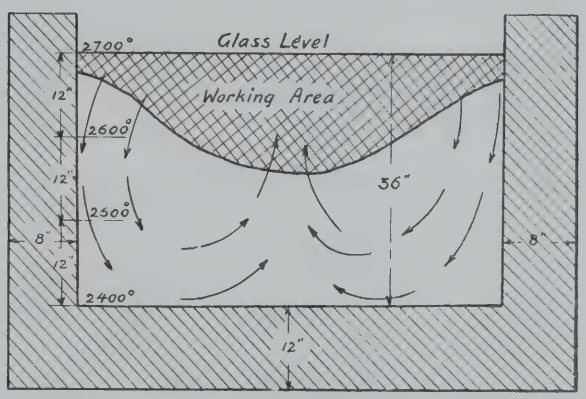


FIG. 7.—*Sketch shewing results in an uninsulated tank.*

by the use of very thick walls, and this, certainly effects some reduction. For instance, J. H. Kruson* has shown that where a 27-in. brick wall gives a heat-loss of 510 B.Th.U. per sq. ft. per hour, a 54-in. wall gives a heat-loss of 330 B.Th.U. per sq. ft. per hour. It must be remembered, however, that a certain proportion of the heat supplied to a kiln is used to heat up the brickwork. A. T. Green† has shown that, to raise a kiln built of 100,000 firebricks, to an average temperature of 500° C., requires the consumption of 7 tons of coal. Moreover, the heat thus stored in the kiln-walls is not available to assist in the burning operation; its only effect is to lengthen the cooling period, for as the burned bricks cool, heat flows from the walls, as well as from the base, back into the cooling bricks. Thus, the heat saved by the use of unnecessarily thick walls, is more than discounted by the loss, by storage, of unavailable heat in the walls and by lengthening the cooling period. It is obvious, therefore, that the ideal construction, consists in the use of the thinnest possible refractory walls, suitably insulated.

As illustrating the large storage of heat in the base of a kiln, it may be mentioned that when a kiln was being rebuilt, the ground 12ft. below the surface was found to be too hot for the men to work in,

* Kruson, Brick & Clay Record, July, 1923.

† A. T. Green. Trans. Ceram. Soc., 1924-5, p. 243.

two weeks after the kiln had been emptied. When the base of a kiln is insulated, the greater part of the heat-loss is eliminated, with the result that the fuel required, per burn, is less and the cooling period is shortened. It has been stated at various times, that the insulation of a kiln will lengthen the cooling process, since the heat-loss through the walls is so greatly reduced. In a kiln constructed on the lines mentioned (Fig. 8) it was found that the cycle was reduced by 28 hours, thus increasing the yearly output of the kiln by 17 per cent.

The saving in fuel in a completely insulated kiln, due to the reduction of radiation and conduction losses, is from 17 to 20 per cent. of the fuel normally consumed, but further fuel-economy results from the much more even temperature which is obtained throughout an insulated kiln. In other words, it is possible to " get the heat down " with the result that the goods, in the lower portion of the kiln, can be properly burned without over-burning those in the upper part. In many plants, it is the practice to re-burn, regularly, the soft or under-burned bricks. This reduces the output of the kiln, and, at the same time, raises the average coal-consumption.

The economies to be obtained by the insulation of pottery kilns, frit-furnaces and enamelling furnaces, may readily be inferred from the foregoing. By the insulation of lime-kilns and rotary cement-kilns a fuel saving of, at least, 8 to 10 per cent. can be effected.

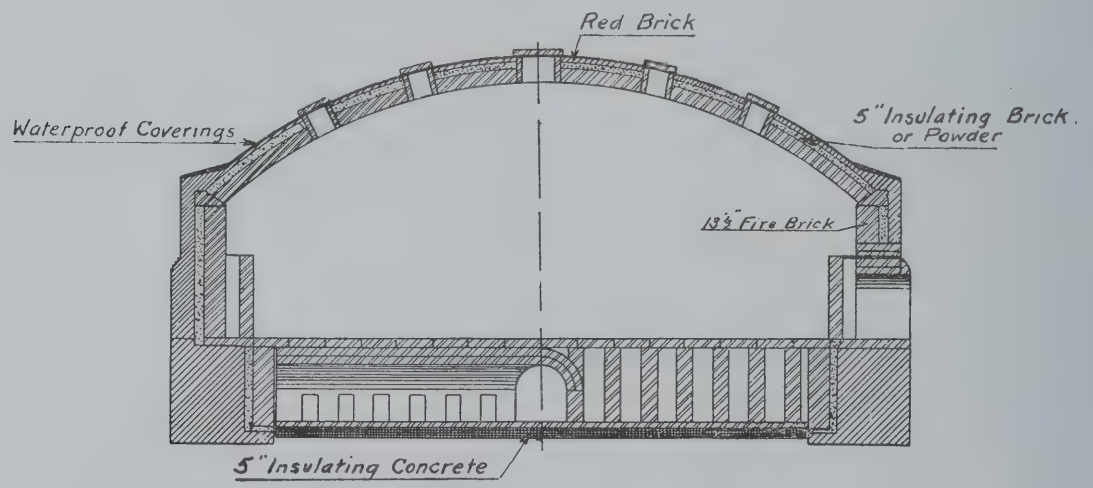


FIG. 8.—*Insulation of Round Down-draught Kiln.*

Boiler plant.

In modern boilers, radiation-losses are low as compared with those from furnaces or kilns, but, since the amount of fuel consumed is high, the saving of even 3 per cent. thereof, is a considerable item in a year's working. For example, in a 500 H.P. boiler operating at 125 per cent. of its rating for 300 days, of 24 hours each, per year, and burning 4 lbs. of coal per H.P., the amount of fuel consumed per year would be :—

$$\frac{500 \times 1.25 \times 300 \times 24 \times 4}{2{,}240} = 8{,}035 \text{ tons.}$$

Assuming the radiation-loss to be 4 per cent. from an uninsulated setting if radiation effected a reduction of 60 per cent. of that loss, saving in fuel would be $8{,}035 \times 0.6 \times 0.04 = 193$ tons per year. If the boiler operated at 250 per cent. of its rating, burning 3.6 lbs. of coal, per H.P., the fuel-consumption would be 14,500 tons. The radiation-loss, would, of course, be lower since this varies as the internal temperature and, although nearly twice as much fuel would be burned, the internal temperature would not be increased by more than 300 or 400° F., and the radiation-loss, in this case, would be, approximately, 2.3 per cent. Thus, the fuel saved by insulation would be 200 tons. It is obvious, therefore, that despite the low radiation-losses, insulation is an essential factor in the economical operation of boilers.

In conclusion, it is hoped that sufficient indication has been given in this somewhat brief resume of the subject, of the importance of insulation as a factor in the problems of fuel economy.

PART X.—OIL POWER.

Chapter 1.

ECONOMIC ASPECTS OF DIRECT FIRING WITH OIL FUEL.

By Alex: H. Hayes.

In a country whose industries have been developed on the basis of a plentiful coal supply, consideration of the economic value of any other fuel must essentially be relative to existing and potential coal supplies. In Great Britain, where the great majority of power-raising and heating plants have been designed for the utilisation of coal and its products, it is natural to examine the value of other fuels on the basis of their availability, heating value and cost of conversion, relative to existing coal supplies. In many partisan attempts at economic comparisons, however, particularly between oil and coal, one or other of various factors is given either undue prominence or is not accorded its full value, in arriving at conclusions.

With respect to the availability of fuel-oil supplies in this country, it is unwise to start with the assumption that, because oil is essentially an imported commodity, it must be relegated to a position of minor importance. Under present conditions petroleum spirit has become an essential in the transport industry, and the world-wide interests in oil which British capital has acquired render petroleum and its products secondary only to our own coal resources. Moreover, in regard to fuel oil, the development of petroleum refining in Great Britain which is proceeding and which will probably extend considerably in the future, places at the disposal of industry a certain amount of the residual fuel oil which, in addition to other fuels such as oil from shale distillation, has a very definite value.

In discussing the economic value of oil fuel for use by direct firing, whether in steam-raising or other types of heating furnaces, it may be admitted at the outset that, on the basis of cost per heat unit, oil fuel at present, and probably for some time in the future, cannot be compared favourably with coal. With oil of a calorific value of, say, 19,000 B.Th.U. costing 80/- a ton, an average bituminous coal of 14,000 B.Th.U. heating value would require to cost nearly 60/- a ton before oil could be competitive on a cost-per-heat-unit basis. In the face of this it is obvious that the reason for the increasing use of fuel oil in many industries must lie in its convenience, economy in application or in some other valuable facility it affords, rather than in its heating value. It cannot be denied that fuel oil has an economic field in many industries; but it is only by a careful examination of all the factors that make for economy that the extent and limitations of that field can be determined.

Character of fuel oils.

It may be advisable, before proceeding further, to briefly survey the types of material which come within the range of fluid fuels suitable for direct firing; for while almost any of the hydrocarbons can, technically, be burned direct in furnaces or similar combustion chambers, the economic application of that process is, in general, confined to such residues as cannot profitably be converted into other products. The relative inefficiency of direct combustion in furnaces and hearths, compared with the high efficiency of the internal combustion engine, rules out of use for direct firing for power production such fuels as are especially suitable for engine operation, since they naturally command a higher price. For example, Diesel-engine oil of 19,500 B.Th.U. on its heat-value basis is worth about 82/- a ton, compared with the fuel oil previously mentioned at 80/- a ton; but since the particular characteristics of Diesel oil render it (at present) more suitable for Diesel-engine operation, its value in that particular application is expressed in its higher price, and its qualities not being of special value in furnace firing, it is relatively uneconomical for that work. Petroleum spirit or petrol, similarly, would be hopelessly extravagant at 1/- a gallon (about £16 a ton) for direct firing.

Fuel oils for direct firing, then, are essentially residues from petroleum distillation, shale and coal distillation, the great bulk being from petroleum. While shale oil, coal tars and similar products cannot

be ignored, they contribute at present only a small proportion to the total of the world's fuel oil supplies. Oil production from the low-temperature distillation of coal (the coal-retorting process which gives the greatest yield of oil) at the moment must be regarded as a technically interesting development of great potentialities, but which has not yet been brought to the plane of practical application in industry; though it may have an important bearing on future fuel oil supplies. At the moment petroleum may be considered as the main source of fuel oil.

Crude petroleum, owing to its complex composition, involving constituents of both high and low volatility, is not utilised for power or heating purposes until it has been refined or subjected to at least a rough separation of its constituents into general groups; though there are a few crude petroleums which, by reason of a negligible content of the lighter fractions, can be used as fuel direct. The simplest treatment is the removal by heat distillation of the more volatile constituents, petrol, naphtha, etc., leaving the heavier residue for use as a fuel for direct firing. The value of the heavier residue when further separated, however, necessitates a more comprehensive heat treatment and the recovery of a number of different fractions, each of which condenses within its own narrow temperature range. The nature of the crude oil and the products required determine the exact nature of the particular fractions that can be separated and the treatment necessary, but the broad division is as follows:—

Products of Petroleum Distillation.

Fraction separated.	Boiling point. Deg. F.	Closed flash point. Deg. F.	Specific gravity.
Petroleum spirit (petrol, naphtha, etc.)	Up to 390	Below 73	.650 to .750
Burning oils (kerosene)	300 to 570	73 to 150	.800 to .825
Solar or gas oils	480 to 640	Above 150	.860 to .870
Lubricating oils	640 to 930	275 to 580	.875 to .935
Fuel oils	Above 570	150 to 200	.870 to .960

It will be seen that the fuel oil is the residual product resulting from the removal of more valuable fractions. Its calorific value varies from 18,000 to 19,500 B.Th.U. per lb., and its composition also varies, according to the origin of the crude, the carbon content ranging from 83 to 88 per cent. and the hydrogen from 10.5 to 12.5 per cent. The sulphur content may vary from 0.03 per cent., as in some Borneo oils, to nearly 4 per cent. as in some Mexican types, but this is not important in oils used for direct firing, as the sulphur is a combustible constituent; the essentials are that the oil shall not flash below a desired point and shall have the necessary calorific value. The British Admiralty specification stipulates 3 per cent. as the permissible maximum for sulphur, while one specification of the United States Bureau of Mines limits the sulphur content to 1 per cent.

An obvious desideratum in fuel oil for use with fine-orifice pressure jets is absence of earthy, carbonaceous, fibrous or gritty matter such as might choke the burners, and this is often specified. The presence of fine sand, although it may not cause choking, tends to enlarge the jet orifices by abrasion and render burner control more difficult. The trouble associated with extraneous matter in the oil has led to the practice, in some plants, of removing dirt by centrifugal separators, and this practice is steadily growing where the highest efficiency is desired.

Maximum viscosity is still stipulated in some specifications, particularly for oils for marine use; but for many industrial purposes very viscous oils are quite suitable for direct firing, as they can readily be rendered mobile for transmission through the feeding and atomising system by the application of moderate heat to the supply tank and pipes—a practice which considerably increases the range of oils suitable for direct firing. Modern practice tends towards the use of heaters in all oil-burning systems, as giving higher efficiency in the furnace and permitting the use of much heavier oils.

While petroleum residue represents the bulk of the fuel oil used, especially for marine purposes, other residues are not without some economic importance. The development of more efficient atomising systems has brought within the sphere of usefulness other fuels, the use of which may extend considerably in the future. Not only shale-oil residues, but crude coal tar from gas and coke-making retorts is found to be suitable, though requiring a high temperature for efficient burning, together with heating means for maintaining fluidity of the fuel in the supply system to the burner. Creosote, obtained by distilling tar, is also a good liquid fuel and lighter than crude tar; while pitch, the residue from tar distillation, can be used, but requires mixing with about 25 per cent. of a lighter oil, such as creosote.

With a view to the extended use of fuel oil, this widening of the range of possible fuels is very desirable. Modern practice in petroleum distillation tends to the increasing conversion of the crude oil into lighter fractions by "cracking," with correspondingly less residual product. Also, the rapid development of the Diesel engine for power purposes is turning the attention of Diesel users to many fuel oils that formerly were considered to be too viscous; for it is found that suitable preheating renders them quite suitable for engine purposes. These two encroachments on furnace oil supplies, while not at the moment restrictive to the development of direct firing, must eventually give greater economic importance to other residues such as those previously mentioned.

OIL-BURNING SYSTEM.

Coming now to the systems by which oil fuel may be converted into heat, we may briefly survey the three main ones now employed, viz., the pressure-jet, steam-jet and air-jet systems. In each the first essential is the disintegration of the liquid fuel into fine particles and the intimate mixing with air under conditions that will permit proper combustion. A judicial comparison of their respective merits would involve close consideration of the details of application, as well as the features of individual apparatus; but without going so far, a general survey of the outstanding features may be made.

Pressure-jet System. This method of fuel disintegration or "atomisation" involves projecting the fluid under pressure through suitable jets so that it forms a finely-divided spray which enters the furnace and therein mixes with the air supplied by forced or induced draught. The pressure system finds universal favour for marine work; it was the first to be perfected at sea, and does not involve the steam consumption required for atomisation by the steam jet. The loss of feed water when steam is used for this purpose renders the steam system quite unsuitable for ships, despite the efficiency it shows on land where feed-water supplies offer no difficulty. A fuel heater forms a desirable part of the pressure-jet system, in order to get proper atomisation, even with the most mobile of fuel oils, while with the heavier types the heater must be considered an essential.

Steam-jet System. For steam-raising plants this system represents the simplest in regard to equipment, as the pressure for atomisation is obtained from the steam boiler, the fuel being injected into the furnace through suitable burners by means of a current of steam. An objection sometimes raised against this method is the loss of steam, which represents from 3 to 4 per cent. of that generated in the boiler; but as against this must be set the low initial cost of the apparatus compared with that involved in the pressure-jet system for pumping and heating equipment, and the cost of the compressor equipment for the air-jet system.

Air-jet System. In this system the liquid fuel is introduced into a stream of compressed air and by contact therewith is atomised and mixed with air, secondary air being introduced as required to complete combustion.

Analysis of the respective merits of these three systems is difficult, as conditions of application determine the advantages to be obtained from either. For steam-raising on ships the pressure-jet has the advantage that it was developed mainly for ships' use and is established; consequently the engineering personnel is familiar with its operation. The steam-jet system is ruled out for the reason already stated, so that the only alternative is the air-jet system. The latter for a long time laboured under the disadvantages associated with inefficient and cumbersome air-compressor plant, though that objection is largely discounted by the compact and efficient designs now available. Atomisation by air has the important feature that greater intimacy of mixing between fuel and air is possible from the outset. Further, the

pressure for atomisation is independent of the fuel supply and consequently the burner has much greater flexibility, as it can be run at much below full-rated capacity and still give the atomisation and intimacy of mixing necessary for high efficiency. It appears probable that in the near future the air-pressure system will find much wider application at sea, in view of its efficiency in land operation.

Apart from marine uses, the air-jet system has much to recommend it from the standpoint of combustion efficiency and flexibility of operation, and it would appear to have a wider scope in industry generally than have either of the other systems. In steam-raising plants when the steam demand is low, the air-pressure burners can be kept operating at just the desired capacity, thus avoiding extinguishing and relighting individual burners and eliminating the blind spots in the furnace which the shutting down of some of the burners would create. With industrial heating furnaces, also, the capacity for regulating the rate of heat generation without lowering the efficiency is a valuable feature.

So far as compressor equipment is concerned, tests have shown that 20 lbs. pressure is the most satisfactory for the work, and that at this pressure 1 lb. of air will effectively atomise 1 lb. of oil. This permits the use of high-speed single-stage compressors without water cooling—a type of apparatus which is cheap and very efficient. The fuel cost for compressor operation and fuel heating for atomisation should not exceed $2\frac{1}{2}$ per cent. of the total fuel consumption.

Steam atomisation lends itself particularly to those steam-raising plants where the possibility of reverting to coal firing as an alternative is desired. The steam-jet equipment is the least costly of the three systems; it is effective, simple to operate and not costly in maintenance. While the fuel consumption represented by the steam used may appear high at first sight, that represents practically the only loss, as there is no large capital cost for plant, with corresponding depreciation and maintenance.

Essentials for economical burning of oil.

Without discussing the respective merits of different burners, it is still possible to indicate the features of operation necessary for efficient combustion of fuel oil in a boiler or other furnace. The chemical reaction of combustion are too well known to require repetition, other than to recall the actual minimum amount of air required. Taking as an example a Mexican fuel oil of 83.52 per cent. carbon, 11.68 per cent. hydrogen and 3.27 per cent. sulphur, the theoretical amount of air at 60° Fahr. is as follows:—For the carbon, $.8352 \times 150 = 125.28$ cu. ft.; for the hydrogen, $.1168 \times 450 = 52.56$ cu. ft.; and for the sulphur, $.0327 \times 65 = 2.1$ cu. ft.; a total of, say, 180 cu. ft., or 13.75 lbs. of air.

In actual practice this must be exceeded, since any attempt to reach the maximum of CO_2 in the flue gases, which would be about 18 per cent. for the average fuel oil, would involve danger of CO formation, with consequent fuel loss. For satisfactory working the figure of 14 per cent. CO_2 may be regarded as about the maximum, and this requires nearly 30 per cent. more air than the theoretical quantity given above. Further, the necessary quantity of air must be introduced under conditions which facilitate rapid and intimate mixing with the fuel. Burners differ considerably in their method of injecting the atomised fuel into the furnace, but in all cases the essential to be aimed at is the creation of a cloud or mist of the finest possible fuel particles, distributed in the combustion chamber so that a turbulent effect is produced by the incoming secondary air to cause intimate mixing. It is acknowledged that mechanically-propelled draught is much preferable to chimney draught for good combustion, and for this reason even air-atomising systems are equipped with impelled draught where the best results are sought. At the same time, care must be taken to avoid stratification of the flowing gases, for that is not only detrimental to intimate mixing and proper combustion, but stratified air acts as an insulator and prevents the full reception of the radiant heat by the furnace walls, boiler, or material to be heated.

In the factor of flame distribution is doubtless to be found the explanation of some low efficiencies with oil firing when applied to furnaces and combustion chambers constructed for coal firing. At the same time, oil firing lends itself very readily to any required distribution of flame, by the introduction of the secondary air as best suited to prolong or shorten the flame's extension. In most applications, however, rapid combustion at the earliest point in the furnace, subject to the avoidance of local overheating and cutting, is aimed at, and the conformation of the furnace walls has a distinct bearing on that. Rapid

combustion is greatly assisted by the presence of incandescent bodies radiating heat, as these at high temperatures have a catalytic effect in accelerating combustion of the fuel-and-air mixture.

Factors in ultimate economy of oil firing.

Coming now to the reasons why fuel oil, despite its relatively high cost per heat unit, finds economical applications in many industries, it is evident that these reasons relate to total cost and output, rather than to initial fuel cost. The examination of a few examples confirms this.

The advantages of cleanliness, facility in bunkering, reduction of firing labour, ease of manipulation and flexibility for marine steam-raising plants, have been too often enumerated to require re-stating here; and in any case the conditions associated with shipping are no criterion for industrial operations on land. In the latter the same factors bear on the case, but in different degree, while there are also other features of oil-fuel use which have special significance in individual industries.

An example is the application of oil firing to heating furnaces for steel billets, plates and similar work. The average efficiency of such furnaces is probably well below 20 per cent., and in some cases below 10 per cent., largely due to the high temperature at which the gases of combustion must leave the furnace, since the material to be heated requires a temperature of 2,200 deg. F. and the gases must necessarily leave at a higher temperature if this is to be attained. Admittedly, of late there has been much attention given to the use of the waste heat in the flue gases (which in such heating furnaces often represents between 50 and 60 per cent. of the fuel consumed) for the purpose of preheating the incoming air, and by this means it is possible to greatly increase the efficiency. In any case, the loss is high and to a great extent unavoidable, and this gives added importance to the time element as a factor in the total cost. Owing to the higher and more quickly attained temperatures possible with oil fuel, the time during which these losses in the flue gas occur is shortened, with corresponding reduction of fuel consumption per unit of throughput. The rapid flow of radiant heat from the luminous flame and the furnace walls is also a factor, since the transmission of heat is not a constant function of temperature difference, but increases for a given temperature difference as the temperatures reach higher figures. Delay in attaining the final critical heat in the heated product is a further serious cause of loss when the required heat is close to the maximum possible in the furnace. Here the advantage of fuel oil's higher possible temperature is obvious, since it again reduces the time during which heat is being lost in the flue gases.

Metallurgical work presents numerous openings for economy by oil firing. Metal-melting furnaces quickly attain high temperatures, giving increased output with regulated heat. For annealing and hardening processes, where temperature control is vital and oxidation must be avoided, oil firing offers distinct advantages which outweigh the higher fuel cost.

In some industrial applications such as for bakeries, food factories and the like, the factor of cleanliness alone is sufficiently important to render oil firing economical. For central heating systems cleanliness and the use of thermostatic control for temperature regulation are important factors. Features which make for economy in oil-fired boiler plants for steam raising are the capacity for maintaining regular steam pressures, since there is no necessity to open the furnace front for fuelling and clinkering; capacity to meet quickly peak loads at any time, or reduce steam output without inefficient combustion; absence of labour expenditure in handling and disposal of furnace ashes. Each industry employing oil fuel finds one or more of its special characteristics of economic value in reducing expenditure in some direction.

To sum up the case, oil firing will show economies compared with coal under certain conditions, when the total cost of plant, fuel, operation and maintenance is set against the value of the output ; and the possibility of economical operation in any given plant will depend upon the extent to which the following factors are involved:—(*a*) Increased output by reason of more rapid heating, attainment of higher temperatures and consequent shorter periods of heat loss; (*b*) reduction in expenditure of labour in fuel handling, firing and control of the heating operations; (*c*) increased use of regulation and control of temperature with consequent saving of products wasted by irregular and imperfect heating.

To obtain an accurate view of the potentialities of oil fuel it is necessary to consider the total costs relative to production, since the economies possible do not lie in the cost per heat unit of fuel, but in the numerous other facilities which it affords for reducing the associated expenses of industrial processes.

Chapter 2.

THE DIESEL ENGINE IN INDUSTRIAL AND MARINE APPLICATIONS.

By Alex: H. Hayes.

The introduction of the internal-combustion engine invented by the late Dr. Rudolf Diesel, marked the development of a phase of power production which has since made phenomenal strides. The progress, however, has been chiefly on the lines of mechanical construction, giving greater reliability and freedom from breakdown; for the first commercial and successful Diesel engine, constructed and completed in Germany in 1897, gave an effective thermal efficiency of nearly 35 per cent.—a figure which is still regarded as good. This high thermal efficiency, compared with reciprocating engines and steam turbines, has resulted in the adoption of the Diesel engine for many purposes, both on land and for ship propulsion, in the face of competition from prime movers using cheaper fuel.

The efficiency of the Diesel or constant-pressure engine is dependent on the ratio of compression, together with the maximum temperature; in the explosion or constant-volume type of engine the efficiency is dependent on the compression ratio alone. As enunciated by Dr. Diesel, the working cycle is characterised by (*a*) production of the highest temperature of the cycle, not by and during combustion, but before and independently of it, solely by compression of air, or a mixture of air and gas; (*b*) gradual introduction of the pulverised fuel into the compressed and heated air during part of the piston's stroke, so that combustion produces no increase in the temperature of the gas. In order to establish the right proportions between the pressures, volumes and temperatures of the gases, combustion is regulated, after ignition, throughout its course by external mechanism. The combustion curve thus obtained is as nearly as possible isothermal.

Since only air is present in the Diesel-engine cylinder during the compression stroke, a compression is possible higher than with the constant-volume or explosion type of engine, in which the permissible compression is limited by the temperature of combustion of the fuel-and-air mixture in the cylinder. This is an important factor in the higher efficiency of the Diesel engine, since the temperature of the compressed air (say 1,000° C.) is higher than that necessary to ignite the incoming fuel, and combustion is, therefore, rapid and complete, the temperature being maintained until completion of combustion. The thermal efficiency of the modern Diesel engine, operating at full-load capacity, may be taken as about 32 to 35 per cent. for the four-stroke cycle type, and 2 or 3 per cent. less for the two-stroke type, based on the actual or brake-horse-power. The distribution of the balance of heat in various losses is shown later in a typical heat balance.

TYPES OF DIESEL ENGINES.

As in other classes of prime movers, the purpose which a Diesel engine serves has a distinct bearing on the type of construction adopted. Thus we find (1) the horizontal, slow-speed, single or multi-cylinder types, from about 75 to 1,500 B.H.P., in use for stationary purposes; (2) vertical, slow-speed types, from 75 to 5,000 B.H.P., for both marine and stationary purposes; (3) vertical, high-speed multi-cylinder types for submarine work and also for the driving of electric generators; (4) double-acting (vertical and horizontal) engines in large sizes up to 12,000 B.H.P., for marine work and other purposes. The conditions of operation determine the suitability or otherwise of any one type for a particular purpose. For example, restrictions of space favour the adoption of the vertical type for marine installations, since it occupies about two-thirds of the floor space of the horizontal type; while with the call for higher powers in marine engines, the double-acting types, both four-stroke and two-stroke cycles, are now coming into wider use. In cases where space is not a serious consideration, the greater accessibility of valves, valve gear and pistons is a factor in favour of the horizontal type which may outweigh the cost of heavier concrete foundations.

The relative advantages of the two-stroke and four-stroke cycle types, respectively, represent a contentious subject which does not come within the scope of the present review. Advocates of the former stress the elimination of exhaust valves and air-inlet valves and valve motion; simplified reversing

mechanism; reduced space and weight; more even torque on the crankshaft and less vibration; reduced flywheel size; less cylinders needed to eliminate the dead centre. Four-cycle advocates, on the other hand, claim the advantages of greater simplicity of the single-acting engine; lower range of temperatures and better cooling effect; more thorough scavenging; better lubrication of pistons, due to a lower temperature, and more effective lubrication of the main crankshaft bearings.

With regard to comparisons of single-acting and double-acting types, the latter shows an increase of about 90 per cent. on the single-acting type, and the rate of heat generation in the combustion space is not increased. One authority gives the weight ratios for the two types as 1.0 : 0.56 for the four-cycle engine and 0.56 : 0.35 for the two-cycle engine. Various difficulties, associated with the arrangement of the bottom cylinder cover, air-inlet, exhaust, starting and fuel-inlet valves, piston-rod clearances and other constructional details, are involved in double-acting engines; but these have been satisfactorily overcome in many designs. The construction and operation of the different types, however, is not the subject of the present discussion, since such matters have been ably dealt with at considerable length by various competent writers.

Fuel Injection. A further differentiation on which opinion is divided, and regarding which the decision is somewhat a matter of personal experience and local conditions, is the method of fuel injection. The high-pressure air compressor required to supply the blast for air-injection of the fuel adds considerably to the cost of the engine, and this naturally directs attention to the possibilities of the airless or " solid " injection method, with its simpler and cheaper mechanism and higher mechanical efficiency. With the latter method, however, it is found that atomisation of the fuel by spraying it under high pressure through small orifices is less efficient than atomisation by air blast; and, consequently, the efficiency of combustion is lower. The net result is not always in favour of airless injection, when taken on the basis of I.H.P., though the difference is not great in the larger sizes of engines, in the fuel consumption per B.H.P.

In the smaller sizes, where the cost of the air compressor tends to be proportionately higher, the balance shows in favour of the airless injection method, which also permits a reduction of the number of moving parts by employing an automatic fuel valve, operated by the pump pressure. This latter feature is chiefly adopted with the smaller-powered engines, the larger airless-injection types usually being equipped with mechanically-operated valves. With airless injection the pressures employed range from very little over 1,000 lbs. to nearly 10,000 lbs. per sq. inch in some cases. With air-blast injection the fuel meets the blast of air compressed to about 1,000 or 1,200 lbs. at the sprayer, and both fuel and air are injected together simultaneously into the combustion space. The fine atomisation thus produced is difficult to obtain with solid injection; and since perfect combustion is dependent on fine atomisation or pulverisation of the fuel and intimacy of mixing with the air, the somewhat higher thermal efficiency is given by air-blast injection, though this is offset by the equipment involved in producing the air blast.

Both systems are in use with practically all types of engines, as also in a third system, employing the Sabathé fuel-injection valve. In this method there are two distinct phases of fuel injection, the first occurring when the piston is at or near the inner dead centre, and the second occurring later.

Stationary Diesel engines.

While the greatest development of the Diesel engine has taken place in marine applications, its adoption for stationary work has also seen considerable progress, though the powers employed do not compare with marine installations. For stationary work it is not usual to instal single units of over 1,000 B.H.P., though some larger ones are to be found. The plant recently installed by the United States Government at the Panama Canal consists of three engines with a combined capacity of about 12,000 H.P., and this is stated to be the largest plant in America. Usually, special local conditions are necessary to justify large Diesel units for stationary purposes, in the face of the high initial cost compared with other prime movers, such as the steam turbine.

The advantages of the Diesel engine for stationary installations are its high thermal efficiency and fuel economy, its capacity to operate on cheap, low-grade fuels, and the fact that it is a clean, self-contained unit and occupies less space than other prime movers. In many situations the ease with which

Diesel fuel can be handled and stored, the absence of ashes and dirt, and the ease with which the plant can be quickly started from cold and full power developed, are important advantages; while, also, there are not the standby losses which are associated with a steam plant. These factors make the Diesel engine a valuable auxiliary for electricity-generating plant, for with it peak loads can readily be met without extending the main plant to give a reserve for such periods. Various power-supply undertakings have installed Diesels for this purpose, one example being the Charing Cross Electric Supply Co., Ltd., which has installed nine engines in sub-stations, operating for peak loads and stand-by purposes in conjunction with the main steam-driven bulk station. Southend-on-Sea Corporation operates four engines in conjunction with its steam-driven generating station; while the same number of engines are similarly operated at Letchworth Electricity Works. Buxton Corporation Electricity Undertaking operates an oil engine in conjunction with gas-engine generating plant for public supply of electricity. Other examples are Chelsea Electric Supply Co., Ltd., which operates three engines in conjunction with a bulk supply from the London Power Company; and Wycombe, where two engines run in conjunction with steam-driven generating plant for public power supply.

Apart from public-supply undertakings, the Diesel engine is steadily finding a wider field as a prime mover for manufacturing and industrial establishments. How far that development will be checked by the adoption of the projected national network under the Electricity Board Scheme remains to be seen. At the moment there are very many cases where Diesel installations would effect important savings, compared with the cost of available public-supply company's current. For intermittent and varying industrial loads, the Diesel installation has distinct advantages over the steam-driven generating plant, particularly for relatively small power demands; it requires much less attention, is simpler to operate and needs less accommodation; also, it is available at the shortest notice for full-load operation.

Even where public-supply company's current is available, private oil-driven installations can often show a distinct saving, after all allowances have been made for interest on capital cost, depreciation and operating costs. An example which the writer personally examined will serve to illustrate this. A business establishment purchasing current from a local supply company, for lighting and power purposes, was paying 3½d. to 4d. per unit, and failing to obtain a cheaper rate for the considerable amount used, decided to install a generating plant on the premises. In all, three vertical solid-injection engine sets were put down, the total capacity being 334 kw., although the maximum load at the time was only 155 kw. It was found that, after including in the operating costs the standing charges for the whole plant of 334 kw., the power was produced at a cost of under 2d. per unit as the year's average. This figure included all running costs, wages and repairs, interest at 5 per cent. and depreciation at 8 per cent.; and the plant was in operation approximately 3,660 hours in the year. During the summer months, with light loads, the monthly costs averaged about 2.33d. per unit, but on fuller loads during the winter the costs dropped to about 1.5d. per unit. It is obvious that, had the plant been required to give considerably above the 47 per cent. of actual capacity which was the maximum demand put upon it, the cost would have dropped still lower. As an example of the operating costs, the details of the year's average may be of interest. These were:—Fuel oil, 0.351d.; lubricating oil, 0.033d.; wages and repairs, 0.305d.; interest and depreciation, 1.31d.; total, 1.999d. In addition, a considerable amount of waste heat from the water jacket and exhaust was available and utilised for steam and heating purposes.

Stationary engine operating costs.

On the question of working costs for stationary installations, some valuable information is contained in the reports of the Diesel Engine Users' Association. The report for 1925-6, covering 37 home power-generating stations and nine overseas stations, shows an average engine cost per unit generated in the home stations of 0.799d., and 0.753d. for the overseas stations. The engines ranged in size from 75 B.H.P. to 1,125 B.H.P., the average being about 750 B.H.P. In some cases the costs were disproportionately high (1.47 with an engine 22 years old), by reason of poor load factor or other special conditions. These latter cannot be taken as criteria; more useful are the following figures representing some of the better cases:—

HEAVY-OIL ENGINE COSTS PER UNIT GENERATED (PENCE).

		Units generated.	No. of Engines.	Total kw. installed.	Fuel.	Lubricating Oil.	Water (including treatment).	Stores.	Wages (Running).	Repairs and Maintenance.	Total.
1	Southend-on-Sea Corp. ...	4,550,570	4	2,580	.329	.099	.014	.003	.073	.133	.651
2	Worthing Corp. Electricity Undertaking	2,753,884	6	1,995	.367	.014	.005	.004	.103	.068	.561
3	Chiswick Elec. Supply Corporation, Ltd.	1,419,222	2	325	.362	.047	.004	.009	.138	.081	.641
4	Crompton & Co., Ltd.	1,385,085	3	1,125	.371	.016	.004	.004	.064	.011	.470
5	Chester Waterworks Co. ...	1,140,000	3	366	.366	.025	.015	.005	.181	.094	.685
6	Birkdale Elec. Supply Co., Ltd.	816,414	2	590	.408	.040	—	.007	.188	.024	.667
7	Buxton Corporation Elec. Undertaking	676,310	1	233	.344	.019	.004	.004	.104	.047	.522
8	Lewes Elec. Supply Co., Ltd.	632,970	4	615	.346	.032	.008	.006	.209	.041	.642
9	Wycombe Elec. L. & Power Co., Ltd.	305,161	2	357	.360	.045	—	.005	.090	.035	.535

With regard to installation (1) in the above table, the engines are ex-submarine high-speed type. The output includes 192,500 units generated by steam raised by engine-exhaust heat. Installation (2) is an all-Diesel main generating station for public supply; (4) is the private generating station of an electrical manufacturing works and is favourably placed in regard to maintenance cost; (5) has a good annual plant load factor; (7) as before mentioned, is run in conjunction with gas-engine generating plant; (8) is an all-Diesel station; and (9) is run in conjunction with steam-driven generating plant.

Taking the whole 46 stations, employing 177 engines of sizes ranging from 60 B.H.P. to 1,125 B.H.P., covered by the report, the overall thermal efficiency was 24.15 per cent. In view of the nature and age of some of the installations, this is not surprisingly low. However, as examples of modern Diesel installations, it is more useful to take the cases detailed above.

Commenting on the foregoing figures of operating costs in England, an American writer states that the average engine cost per unit generated for four American stations was about 0.425d. In view of the fact that fuel costs bulk so largely in the English figures, the difference is not remarkable. The following figures are from a report by the National Electric Light Association, New York, and relate to seven different plants:—

OPERATING COSTS OF AMERICAN DIESEL PLANTS (PENCE PER UNIT GENERATED).

Plant No.	1	2	3	4	5	6	7
Fuel	.148	.1505	.233	.297	.5835	.463	.421
Labour	.0905	.0985	.120	.1715	.978	.343	.2645
Lubricants	.019	.0215	.048	.0225	.1475	.0485	.0665
Maintenance...	.1195	.0345	.1605	.025	.527	.0625	.1005
Miscellaneous		.0115	.004	—	.052	.038	.2025
Totals	.377	.3165	.5655	.516	2.288	.955	1.055

During the last four years the maintenance cost in Britain has been considerably reduced, due to the accumulation of experience in operating methods and also the increasing average size of engines installed. In 1923-4, the average of the 37 home stations previously mentioned was about 0.2d. per unit generated; in 1925-6 it was only 0.137d. The individual figures of maintenance and repair costs indicate that with reasonably modern installations an average of 0.05d. is practicable.

MARINE DIESEL INSTALLATIONS.

Probably the clearest indication of the wide adoption of the Diesel engine for marine purposes is seen in the annual returns issued by Lloyd's Register of Shipping. This report for the year ended June, 1927, shows 548 motorships, totalling 2,610,705 tons, either actually classified by the Society or completing under survey. The following table, showing the numbers and tonnage of the world's motorships of 100 tons and over, as recorded in the Register Book, indicates the progress of this method of propulsion:—

Year.	Motorships (including Auxiliary Vessels). No.	Gross Tons.	Year.	Motorships (including Auxiliary Vessels). No.	Gross Tons.
1914	297	234,287	1923	1,795	1,666,385
1919	912	752,606	1924	1,950	1,975,798
1920	1,178	955,810	1925	2,145	2,714,073
1921	1,473	1,248,800	1926	2,343	3,493,284
1922	1,620	1,542,160	1927	2,552	4,270,824

There were thus 2,552 motorships afloat in July, 1927, but more than two-thirds of this number comprise vessels under 1,000 tons. On the other hand, there are included 241 motorships of over 6,000 tons each, aggregating 2,024,958 tons gross, and 88 of these, aggregating 956,081 tons, are each over 8,000 tons.

The total steam and motor tonnage (including auxiliary vessels) throughout the world at the end of June, 1927, was 63,267,302 tons gross. Of this total, 49,767,495 tons was propelled by reciprocating steam engines, 9,228,983 by steam turbines, and 4,270,824 tons by motors. The present relative position of the motorship is seen by reference to the shipbuilding returns for the quarter ended September, 1927. These returns, compiled by Lloyd's Register, show a total tonnage under construction in Great Britain and Ireland, amounting to 1,536,416 tons gross, of which 881,489 tons represented steamers and 653,342 tons motorships; while, in the rest of the world, the proportion was greatly in favour of motorships, the figures being: Steamers, 586,903 tons gross; motorships, 936,018 tons gross. The total tonnage of motorships under construction, in all countries, at the end of September, 1927, thus exceeded steam tonnage by 120,668 tons, being 1,589,510 as compared with 1,468,842.

At the same date there were under construction in various countries the following engines intended for propulsion of sea-going vessels:—

	Reciprocating Steam Engines.		Steam Turbines.		Oil Engines.	
	No.	I.H.P.	No.	S.H.P.	No.	I.H.P.
Great Britain and Ireland	224	394,224	19	193,800	98	356,440
Other Countries	106	174,745	10	116,100*	242	807,190
Totals	330	568,969	29	309,900*	340	1,163,630

* Excluding turbine engines building in Germany, for which figures are not available.

The advantages which have led to the wide adoption of Diesel engines for ships' propulsion are now fairly well known, and may be summarised as follows: Reduction of space required for machinery and, hence, increased cargo space; reduction in attendance and absence of stokers and coal trimmers; economy of fuel, the consumption ranging from about 0.4 to 0.45 lbs. per B.H.P. per hour; convenience of storage of liquid fuel compared with coal; increase in the radius of operation of the vessel; elimination of large funnels and smoke; quick starting and development of full power; small standby losses, as fuel consumption ceases when the engines stop; rapidity, ease and cleanliness of bunkering with oil.

With regard to types of engines, those that find application in marine work are various, including both two-stroke and four-stroke cycles, single and double acting; opposed-piston; and the double-acting piston and moving-cylinder type. It is not within the writer's province to discuss the features of these different types and designs; for the condition of operation, personal preference and other factors affect the choice. It may, however, be remarked in passing that the multiplicity of types available is confusing to the would-be user, and there is scope for some competent authority in reducing the choice to a basis which will permit reasoned examination of the respective merits of available engines. Some form of standardisation would not only assist in the ready adoption of Diesel propulsion, but would also greatly simplify the business of training engineers for the competent handling of such installations.

Sizes of Marine Engines. As previously indicated, much larger horse-powers per unit are employed in marine work than on land. The " Alcantara," until recently the largest motorship afloat, is equipped with two eight-cylinder, four-cycle double-acting units, each of 7,500 S.H.P.; and this record is now exceeded by the " Saturnia," mentioned later. The " Augustus " also exceeds the " Alcantara " in total power, having four double-acting two-stroke cycle engines, each normally developing 6,250 B.H.P. at 120 r.p.m. and capable of 7,000 B.H.P. at 125 r.p.m., the vessel's speed being 21 knots maximum. Other liners now under construction will carry engines of approaching 4,000 B.H.P. each. Not only in liners, but also in cargo boats, are high-powered units employed; for the " Dunster Grange," the largest refrigerator ship afloat and launched in October, 1927, is fitted with twin sets of six-cylinder engines developing together 6,400 B.H.P. at 117 r.p.m.

Supercharging.

A development which has been much discussed of late in marine engineering circles is the adoption of supercharging or forced induction, in order to increase the output. The latest example is seen in the new 23,500-ton Cosulich liner " Saturnia," which is equipped with two B. & W.-type eight-cylinder, four-cycle, double-acting engines, each developing considerably over 10,000 B.H.P. at 125 r.p.m. when supercharged, and about 9,000 B.H.P. without supercharging. The superchargers in this case are electrically-driven blowers which can be brought into service as required at the shortest notice. During the official trials of this vessel a speed of 21.3 knots was attained, the two engines developing actually 22,000 B.H.P. under supercharging conditions.

While the practice of supercharging enables the output of an engine to be increased by 20 per cent. or more, thus reducing the weight of machinery and installation cost per horse-power, the general practice, at the present time, appears to be to consider this extra power as an available reserve for emergency conditions rather than as a standard output. Such a reserve of power for short periods is valuable in maintaining schedule times, catching tides and so forth. It is probable that this attitude will continue until more experience has been accumulated in regard to the stress effects of supercharged operation over long periods.

The maximum increase obtainable by reason of forced induction is governed by the compression pressure at which the engine will safely start; and by increasing the compression space this maximum compression pressure may be kept within reasonable limits and a considerable increase in power (well over 20 per cent.) be obtained. The temperatures, also, can be kept down to reasonable figures by giving sufficient excess of air and by suitable valve timing. Nevertheless, the increased output involves a corresponding increase in fuel consumption, and if the actual work done is proportional to the fuel used the heat stresses will be proportionately higher than without supercharging. This fact would appear to indicate the inadvisability of continuous supercharged operation, with the present slow-speed engines of

large cylinder diameter. With high-speed engines, where the cylinders are smaller and the wall thicknesses less, this objection is not so pronounced; while, also, the complexity and lack of symmetry in the four-stroke cycle engine renders heat stresses more serious than in the two-stroke cycle engine.

A line of development which will probably be followed closely in the near future is that which leads to higher engine speeds in conjunction with supercharging. This is indicated by the results obtained with the Buchi system, employing an exhaust gas turbine to drive a supercharging blower. Quite remarkable increases of power have been obtained; but it must be admitted that the vessels with which the results were obtained were on short-voyage service and were equipped with high-speed submarine-type engines, involving cylinders of moderate size and high piston speeds. The conditions are not strictly comparable with those in which an engine is required to maintain its full operation for days on end, and where safety and reliability are the primary considerations. It should be mentioned, as a factor bearing on this question, that the highest mechanical efficiency is found in those Diesel engines which have low rotative and piston speeds and light, well-balanced reciprocating parts.

At the present stage of marine Diesel engine development, supercharging must be regarded as particularly applicable to high-speed vessels on short-passage service, and also as a means of obtaining a reserve of power for short periods in vessels whose normal requirements are met without supercharging. This does not mean that supercharging will not become standard practice in the future, though the general adoption of the practice would appear to call for still further advances in materials of construction for engines, and probably, also, a reconsideration of the whole question of desirable speeds for marine internal-combustion engines.

Other developments.

The Scott-Still System. A special development which calls for attention is the Scott-Still engine, which may be described with reference to two sets recently installed in the motorship " Eurybates." Each of these engines has five combustion cylinders, 27in. diameter by 45in. stroke, working on the two-stroke cycle principle in combination with two steam cylinders, 24in. diameter by 45in. stroke, which utilise regenerated steam from the cylinder jackets and from the exhaust gases. The normal power of the engines combined is 5,000 B.H.P. at 105 revolutions per minute at sea.

Two regenerators are provided, through which the exhaust gases from the main engines pass in series. The larger one is designed for a working pressure of 180 lbs. per square inch, while the smaller one works at 15 lbs. pressure. Oil burners are fitted to the larger boiler and are used for generating steam for manoeuvring purposes. At sea the burners are shut off. The smaller regenerator serves also as a reservoir for the cylinder jackets, and connecting pipes supply the jackets with water which returns by natural thermal circulation to the regenerator in the form of water at increased temperature and steam.

The steam obtained by this process of heat recovery is used in the steam cylinders of the main engines, and further work is obtained by using the exhaust steam from the main engine cylinders in a steam turbine which drives the scavenging air blowers. The exhaust steam from the turbine passes in the usual way to the condenser.

These engines can be operated on steam alone, with, of course, reduced power. The first vessel fitted with Scott-Still engines, the " Dolius," has covered 200,000 miles in the past three and a half years, with very economical results.

Diesel Electric Drive. The conversion, by the United States Shipping Board, of various vessels to Diesel-electric drive draws attention to another marine development of interest. Electric propulsion is rapidly increasing in importance, and the choice appears to lie between turbine generation and Diesel generation, the former at present having the lead. One advantage which may prove favourable for the Diesel engine in this rivalry is the possibility it affords of clear decks, by employing a number of engines, direct-coupled to generators and exciters, of, say, 2,500 H.P. each. By this means very large ships' powers can be installed without departing from standard patterns of engines, with consequent simplification of operation and greater reliability.

FUEL FOR DIESEL ENGINES.

During the earlier development of the Diesel engine the fuel employed was almost entirely "straight-run" residual oil from the low-pressure distillation of petroleum, after the recovery of the petrol and other light fractions. The suitable grades of this residue became known as Diesel oil and commanded a higher price than the heavier grades used for direct firing and classed generally as boiler fuel oils. The specific gravity of Diesel oil was usually below .90 at 15° C., at which temperature it had to be liquid to enable ready transit through the engine's supply system and atomiser. The gross calorific value of the oil ranged round 19,500 B.Th.U. per lb.

Of late, however, it has been found that heavier residues can be successfully employed for Diesel operation, and it is not uncommon to find even the heavy Mexican fuel oils, up to 0.97 specific gravity, so used. A number of British electric-power stations regularly use a proportion of boiler fuel-oil in Diesels, with satisfactory results.

Many engines will run on any petroleum fuel-oil if it is delivered to the engine in a clean, free-flowing condition. Specific gravity is a minor consideration, as the necessary fluidity is readily obtained by heating the oil by coils or hot-water jackets in the supply tank. For the most satisfactory operation of Diesel engines, the following characteristics of the oil are recommended: Water not over 1 per cent.; flash point not below 150° F.; free acid not over a slight trace; acid not over 0.05 per cent.; sulphur not over 2.5 per cent. In some cases it is found advisable to use a lighter oil for starting up and until the engine is warmed to the point of readily handling the heavier grade; and in such cases it is desirable, before shutting down, to revert to the lighter oil so that the fuel lines will not be left loaded with the heavier oil for the next start.

The asphaltum content of a fuel-oil, as determined by standard methods, is not a definite index to the suitability of fuel oil. Some oil containing a high percentage of asphaltum shows relatively low "residue" by the preferable method of reducing a sample to constant weight at 300° C., whereas another oil containing a low percentage of asphaltum has shown a very high percentage of "residue." Depending upon the chemical composition of the so-called asphaltum, more or less of it will be capable of combustion in a Diesel engine at the temperature and within the time available.

If fuel oil contains dirt in suspension or more than 1 per cent. of water, these should be removed by passing the oil through a centrifugal separator, filter, or a combination of the two. This is a practice which generally proves economical.

SUBMERGED COMBUSTION.

By Alex: H. Hayes.

A feature of combustion systems generally, which has for many years exercised the minds of engineers, is the loss of available heat through radiation and flue-discharges. It is not surprising, then, that the engineer of fifty years ago was intrigued with the idea of combusting fuel directly in a fluid to be heated, in order to extract the greatest possible amount of the heat generated. At what date the conception was initiated is immaterial; the first practical proposition appears to have been put forward by Collier, who patented, in 1886, a device which is noteworthy as containing in elementary form all the requirements for obtaining combustion under water.

While submerged combustion was established as a technical possibility, it is evident that the efficiency and practical application of Collier's attempt were not sufficiently pronounced to give the process immediate industrial value. However, from that time onwards, various experimenters have followed Collier's lead, though only within the last year or two can the process be said to have been raised to an industrial position.

The difficulties that hampered the earlier development of submerged combustion mainly resulted from imperfect appreciation of first principles; in fact, so much so has this been the case, that many of the attempts made in the years following the first practical presentation of the idea, can only be regarded as retrograde in character. In order to assess the value of the contributions to the art made by different experimenters, it is necessary to review briefly the essential requirements for combusting a fuel-and-air mixture under conditions of submergence.

Essential requirements.

The conception of combustion in direct and intimate contact with a fluid to be heated, so that no radiation losses can occur and the hot products of combustion themselves are utilised, implies perfect combustion of the fuel to CO_2 and the introduction of the minimum of valueless inert gases during the process. Unquestionably, this is where the earlier experimenters failed.

To combust properly any fuel completely surrounded by a non-combustible fluid, provision must be made for the following: (1) Adequate supply of oxygen (air) to complete the chemical change to CO_2; (2) Intimate mixture of air and fuel to ensure combustion sufficiently rapid to be complete during the time it can, under the operating conditions, occupy the combustion space; (3) Injection of the fuel-and-air mixture into the fluid under sufficient pressure to maintain a displacement of the combustion gases downwards into the liquid in which the burner is immersed; (4) The provision of means for sustaining ignition after submergence; (5) The avoidance of a chilling effect through conduction of heat by the fluid, such as would result in imperfect combustion; (6) The avoidance of heat effects on the burner parts which would result in deterioration or destruction; (7) The avoidance of pre-ignition due to conduction of heat by the burner parts to the fuel supply.

The first requirement, being a matter of elementary chemistry, was appreciated generally at the outset; but the necessity for very intimate mixing seems to have had only casual attention. This, however, is not surprising, when it is remembered that the stratification of flowing gases and fluids has only been really understood during recent years. In the case of submerged combustion this is a vital matter, since the conditions of operation strictly limit the time during which combustion is possible before the inevitable quenching takes place. The importance of this will be seen when it is recalled that the complete reaction of combustion to CO_2 has to take place in a fraction of a second in the restricted area of the combustion chamber and nozzle of the burner.

The third requirement, pressure of injection, was obvious from the outset, and the problems associated with it were chiefly of a mechanical nature in the provision of dependable and efficient compressor and blowing apparatus, giving a steady and controllable flow of air. The fourth requirement, the maintenance of ignition conditions, appears to have been a stumbling block, as it is inter-related to the questions of chilling and overheating of the burner parts. A primitive type of combustion chamber, say, a heavy metal tube into which the mixture is injected for combustion, when heated to the temperature necessary for ignition and perfect combustion of the incoming fuel, may be submerged partially without affecting the

reaction; but if submerged completely the conduction of heat by the surrounding fluid demands a very nice balance of rate of heat conduction and rate of fuel supply, *i.e.*, rate of heat generation, if chilling below the ignition point (quite apart from the prevention of perfect combustion) is to be avoided. Any variation from the requisite balance of these factors must result either in destruction of the burner through overheating, or chilling of the combustion chamber and resultant imperfect combustion. It is not surprising, then, that burners approximating to the primitive type failed under any but the narrowest applications in industry, despite demonstrated efficiency under carefully controlled conditions.

The difficulty in maintaining ignition and the necessity of avoiding chilling of the fuel-and-air mixture during combustion, led some experimenters to provide a hot spot in the combustion chamber, isolated from the outer walls. It was found, however, that this was difficult to maintain, owing to the destructive nature of the flame; and burners constructed with such hot spots, which necessarily took the form of protuberances of some sort, tended to be rapidly burned out or fused. The difficulties associated with overheating include the danger of lighting back into the fuel-supply stream. Overheating and lighting back, in some designs, has been a serious trouble; for no expedients such as the introduction of gauzes, nests of tubes and the like, are effective in preventing it, since they rapidly acquire by conduction a temperature sufficient to ignite the mixture on the supply side.

Considering together the requirements (4) and (5) above mentioned, the use of a refractory material for the combustion chamber offers important advantages. A well-known characteristic of both metals and refractories on attaining a temperature of 850° C. or over, is a catalytic influence on the combustible mixture, accelerating the rate of combustion and hence rendering combustion complete in a shorter space of time. Metals, however, at such a temperature would be liable to rapid deterioration, and, therefore, have very limited applications, while refractories are subject to no such close limitations, provided their mechanical weaknesses are accommodated in the construction of the apparatus. The absorbtive capacity of a refractory for fluids, particularly water, however, necessitates that it be kept from direct contact with the fluid, and this involves a casing such as metal. This introduces complications due to differences in expansion, tending to mechanical destruction of the parts, but the problem is a mechanical one capable of mechanical solution.

The steam-gas mixture.

It will be understood that the product resulting from submerged combustion in water is a steam-gas mixture, the gases being nitrogen and CO_2. Since the process was primarily associated with steam raising as its objective, it is well to bear in mind the distinction between its product and the pure steam from ordinary boiler practice. When using a normal town's gas, the steam-gas mixture produced by submerged combustion may be taken as consisting of, approximately, 50 per cent. steam and 50 per cent. gases of combustion, and in the utilisation of such a mixture Dalton's Laws of pressures of mixed gases and vapours apply. Accordingly, in the mixture the total pressure is equal to the sum of the " partial pressures " of the constituents, and the steam-gas mixture behaves as superheated steam down to atmospheric pressure. Expanded to atmosphere, the temperature, by the same law becomes 80° C. in a mixture of 50 per cent. steam and 50 per cent. combustion gases. Thermally, therefore, the steam leaves the exhaust under conditions of partial vacuum.

Since the energy imparted to a gas is a function of its specific heat, and the gas of the steam-gas mixture has a low specific heat, it is obvious that the contained heat at any given pressure will be lower than with pure steam. This has been made the ground of a contention against the economic value of the steam-gas mixture for power purposes; but the contention is not valid, and can only be supported by comparing the efficiency of a given engine operating on pure steam and steam-gas respectively. This ignores the essential economic relationship between the actual energy in the fluid medium and the fuel expended in its production, which is the real basis of comparison.

The application of steam-gas to existing plant does not permit the maximum advantage to be taken of its properties; but before its value for power production can be put on a comparative basis, considerable experimental work will be required. There is too little information available at present to permit the expression of an authoritative opinion; though such data as are available indicate a considerable field of usefulness in non-condensing plant.

In passing, it may be well to refute the claims that have, in the past, occasionally been made for efficiences of over 100 per cent. for steam raising by submerged combustion. It is evident that these efficiencies were only apparent, and resulted from a feature peculiar to submerged combustion under some conditions. During the earlier experimental work it was found that when the combustion chamber nozzle was only slightly submerged, it was possible for the steam-gas mixture to carry over with it in

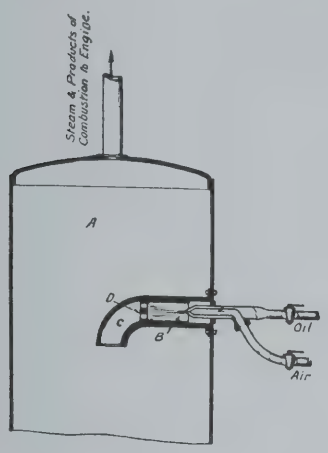


FIG. 1.—*Collier*, 1886.

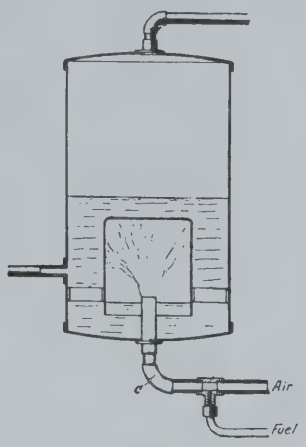


FIG. 2.—*Brunler*, 1893.

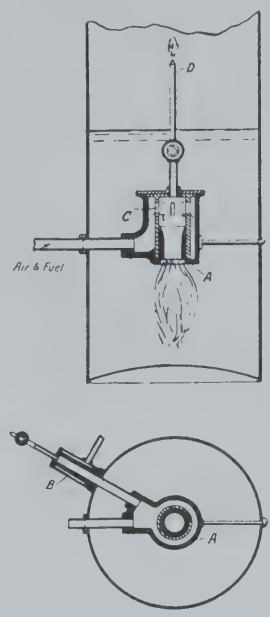


FIG. 3.—*Brunler*, 1898.

finely-divided form a considerable quantity of water, the actual steam produced being much less than the apparent amount. The simple process of ascertaining the volume of water removed from the boiler by combusting a given volume of fuel of known heat value, is in such cases misleading, owing to the low thermal value of such a steam-gas-water mixture, and does not give a true indication of the efficiency of the process.

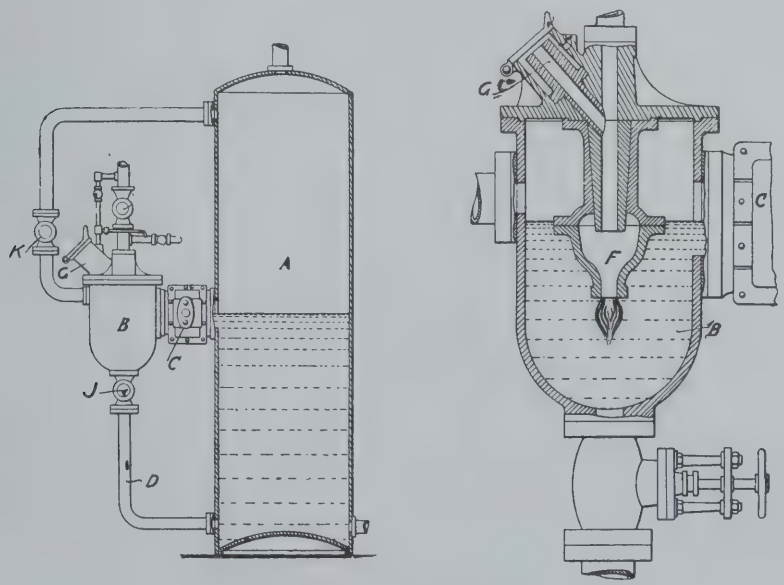


FIG. 4.—*Brunler*, 1903.

Modern developments of the combustion unit.

To appreciate the present state of advancement of the art of submerged combustion it is necessary to briefly survey the developments through which the apparatus has passed. Strictly, the subject should be considered from two standpoints: (1) The construction and operation of the combustion unit as such and (2) the development of plant and appliances for the effective application of the principle. As already indicated, much of the early work had steam-raising for power purposes as the objective, though the application to chemical processes and the like was from time to time cited.

Collier's design, in the year 1886, is shown, in principle, in Fig. 1. In this he produced in elementary form all the essentials for combusting a fuel-air mixture under conditions of submergence in the fluid to be heated; though the apparatus lacked certain features necessary for practical industrial

application. The fuel and air, mixing in a refractory-lined combustion chamber *B*, discharge through the nozzle *C*, into the fluid in the boiler *A*. To ensure maintained ignition of the fuel mixture, a perforated tile *D* is provided to form a hot spot. Collier claimed as the most important feature of the invention, the combination of the steam and the gases of combustion as an elastic medium in which all the

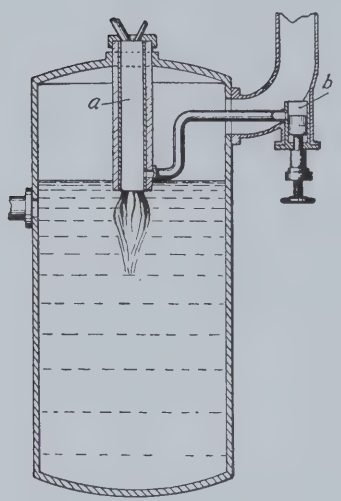


FIG. 5.—*Brunler*, 1907.

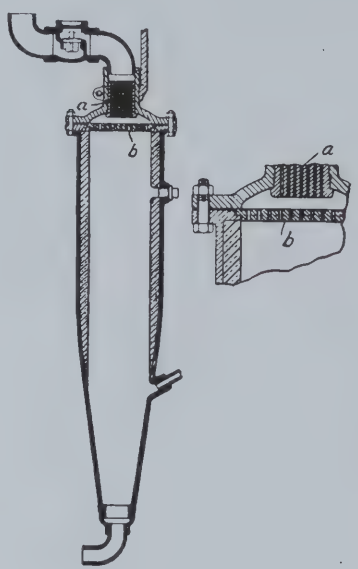


FIG. 6.—*Evans*, 1909.

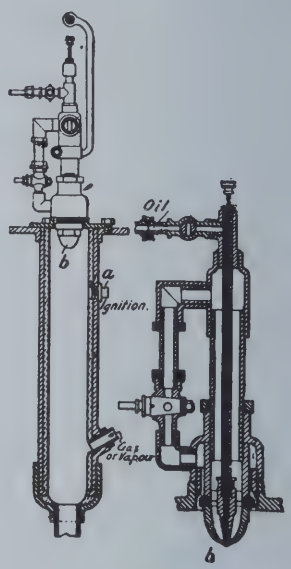


FIG. 7.—*Evans*, 1909.

useful heat in those gases is made available for power production. He also suggested applying the apparatus at other points in the course of the steam travel to give superheating.

Critical examination of the design shows the defects of imperfect mixing of the air and fuel prior to combustion, tending to allow the mixture to be discharged before combustion is complete, and the certainty of the hot spot being quickly cut away by the flame. In the event of perfect combustion taking place, rapid destruction of the combustion chamber would be inevitable, as the majority of that portion of the apparatus is in the steam space, only the nozzle being immersed. Submergence of the combustion chamber sufficient to cool it to the point of avoiding destruction by over-heating would render the operation inelastic, since a variation of either fluid level or rate of heat generation would result in chilling or overheating respectively.

In 1893, seven years after Collier's invention, Oscar Brunler introduced the idea of a diving bell, as shown in Fig. 2. Comparison with Collier's design will indicate that all the defects of the latter are embodied in Brunler's apparatus, which cannot be said to have contributed any new departure in principle. The mixing of the air and fuel at the point shown, involves combustion in the portion *C*, which was, in fact, kept red hot by external heat.

Scholten and De Villeneuve, in 1894, brought out a design in which the same defects were present, in addition to the danger of lighting back. A design by Smethurst in the same year attempted to avoid the latter trouble by passing the combustible mixture through gauzes and a nest of tubes cooled so that combustion could be confined to a bell chamber; but in this apparatus, again, all the essentials for complete combustion were not present. The use of gauzes to prevent back-firing was a prominent feature of a further attempt by Smethurst in 1909; but it was merely a matter of time for the protection device to become sufficiently hot to cause ignition on the intake side.

Some advance was made by Brunler in 1898, by the arrangement shown in Fig. 3, though it does not appear to have been followed up in his later modifications. The main burner portion *A* is supplemented by an auxiliary burner *B*, which serves to preheat the main burner and ensure ignition. The jacket formed by the portion *C* was assumed to act as a preheater, but there is nothing to prevent ignition taking place on both sides of it. A portion of the fuel is combusted in the steam space *D* to give superheating.

A modified form of burner introduced by Brunler in 1903, and shown in Fig. 4, was in some respects similar to his earlier design of 1898, in that it embodied a pilot lamp for ensuring ignition. The arrangement comprises a small steam-generating boiler *B*, connected with a main boiler *A*, the burner operating in the former and supplying steam to the latter, with a circulatory system through the pipe *D*. The valves *C*, *J* and *K* are for isolating the generator *B* from the boiler *A*, when the plant is started by lighting the pilot lamp at *G*. It is, however, obvious that a constant water level on the main boiler must be maintained, as variation involves the risk of over-heating and destruction of the burner, through variation of the water level in the generator.

In an elaborate design introduced by Hauptmann in 1906, an apparatus was superimposed on the boiler, whereby the steam generated and products of combustion were utilised to preheat and volatilise the oil fuel, the steam-gas circulating round a coil which conducted the air and fuel to the burner. The latter was not actually submerged, but discharged on to the surface of the liquid. Superheating of the steam was claimed for this design, but the construction cannot be said to have contributed anything important to the progress of the art. The same might be said of a further modification introduced by Brunler in 1906, which provided for a combustion tube with walls sufficiently thick to retain the necessary heat to ensure complete combustion, the walls being then fused away by the flame until they reached a thickness at which they became cooled by the fluid sufficiently to resist the fusing action. Such an operation obviously requires the maintenance of an exact balance between water level and rate of heat generation.

An apparatus was put forward by Brunler, in the same year, for the production of nitric acid through the fixation of nitrogen and oxygen introduced into a partly submerged spherical combustion chamber, with fuel nozzles converging on the centre and discharging their products into water. It is conceivable that

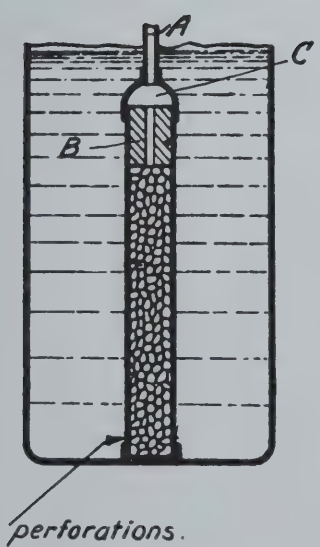


FIG. 8.—*Bone, Wilson and McCourt*, 1911.

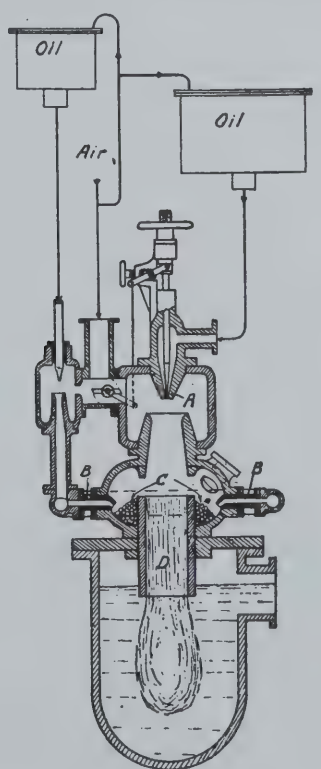


FIG. 9.—*Kohn*, 1923.

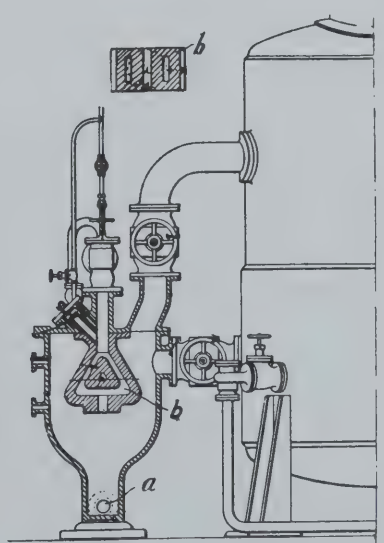


FIG. 10.—*Brunler and Mackay*, 1923.

for a short period the desired effect would be produced, though it is difficult to see how overheating of the top portion of the cast-iron combustion chamber, although lined with refractory bricks, could be avoided, when the temperature necessary for fixation is recalled. The apparatus represented a variation in application rather than a development of the principle.

The design shown in Fig. 5 represents an attempt to deal with the problem of entrained water in the steam-gas mixture. Finding that a burner only partially submerged caused the gases to pass merely through the upper layers of the water, carrying away with them particles of water, Brunler, in 1907, attempted to vaporise that entrained water by carrying part of the products of combustion through the branch pipe and valve *b*, to superheat the steam-gas mixture produced in the boiler. It is, however, very difficult to vaporise by such means and the water is liable to remain in the mixture. Nothing less than perfect combustion could possibly be effective for the purpose. A modification introduced by Brunler, in 1909, was the introduction of the feed water at the combustion chamber tip, so that it entered the boiler at a point adjacent to the flame. The advantage of this is not very apparent. In other respects the burner presented no advance on Brunler's earlier designs.

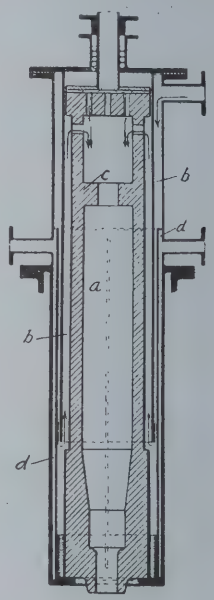


FIG. 11.—*Smith*, 1925.

The desirability of an extended and incandescent combustion chamber with refractory walls appears to have been appreciated by Evans, who introduced, in 1909, the burner shown in Fig. 6. The introduction of the perforated plug *a* and the perforated disc at *b*, however, offers no protection in preventing lighting back, since by conduction they would become hot enough to support combustion on either side. Another design by Evans in the same year (Fig. 7) provides much more effective means for atomising the fuel and producing both primary and secondary combustion. The mixing is done in the top portion of the combustion chamber and the oil discharged through the jet (at *b*), surrounded by air. A refractory lining for the combustion chamber is provided, and ignition means introduced (at *a*) similar to the previously-mentioned design. In many respects this design meets the requirements for proper combustion better than its predecessors.

A distinct departure from previous practice was introduced by Bone, Wilson and McCourt, in 1911. In this design (Fig. 8) the explosive mixture is supplied by the pipe *A*, through a fireclay plug or nozzle *B*, to a chamber packed with granular refractory material, in which combustion takes place, the products discharging at the lower end. Mixing occurs in the supply tube and the space *C* above the fireclay plug, and is also assisted by impinging on the granules in the combustion chamber. Combustion occurring around these granules keeps them incandescent and maintains the desired hot catalyst in the combustion area. The difficulty encountered was the tendency of the refractory granules to fuse into a mass and obstruct the passage of the gases, the heat attained under the conditions depicted being the maximum possible for the rate of fuel supply.

In 1911, Brunler patented a burner which was substantially like his earlier design (Fig. 4) except that a refractory saucer or plug was introduced in the combustion chamber to intercept the flame and form a hot spot for maintaining ignition. The efficiency of this device in assisting combustion is obviously a measure of its own liability to destruction, in the absence of any means for preventing it from becoming overheated. It appears to have been discarded for this or similar reasons.

An elaborate apparatus designed by Benedict, in 1912, contained practically no new departure, except an arrangement whereby the products of combustion were carried through a cooling tube and discharged into a chamber where tar and carbon from the gas were supposed to precipitate, the gaseous product of combustion being then discharged into the fluid through a dome nozzle supplied with a non-return valve.

After a lapse of eleven years, Kohn appears to have been the next recruit to the ranks of experimenters in submerged combustion. In his design (Fig. 9) he shows appreciation of one of the essentials, in that it embodied an attempt to maintain an incandescent catalytic surface in the chamber. The oil fuel is fed, not only to the main burner *A*, but also to auxiliary burners *B*, *B*, impinging on granular refractory material *C*, which is thus kept as an incandescent mass round the path of the main fuel and air mixture. This would greatly assist in getting proper combustion, though the method of spraying the fuel suggests a likelihood of unatomised oil passing through the combustion chamber, owing to the absence of adequate means for producing turbulence for intimate mixing. To a great extent this apparatus was anticipated by Brunler's design of 1898 (Fig. 3) where an auxiliary burner is also employed.

Following his father's work, Brunler, Junr., together with Mackay, in 1923, attempted to improve on the construction put forward by the elder Brunler involving the use of a pilot burner. The essential modification (Fig. 10) is in the use of a flat tubular combustion chamber *b*, in which the main passage divides about a water-cooled bridge piece, and unites again in a common orifice discharging into the fluid. The general arrangement is similar to that shown in Fig. 4, except that a drain cock is introduced at *a* for blowing down the lime and carbonates which precipitate in the generator body. The main steam-and-water container remains free of sludge, since the system is not circulatory, as in the previous arrangement. The claims for improvement are based on the provision of the water-cooled bridge piece in the burner, upon which the pilot flame first plays to bring the surface to red heat. It is obvious that in this construction the maintenance of the water level within close limits is vital, if over-cooling on the one hand and destruction of the burner on the other are to be avoided.

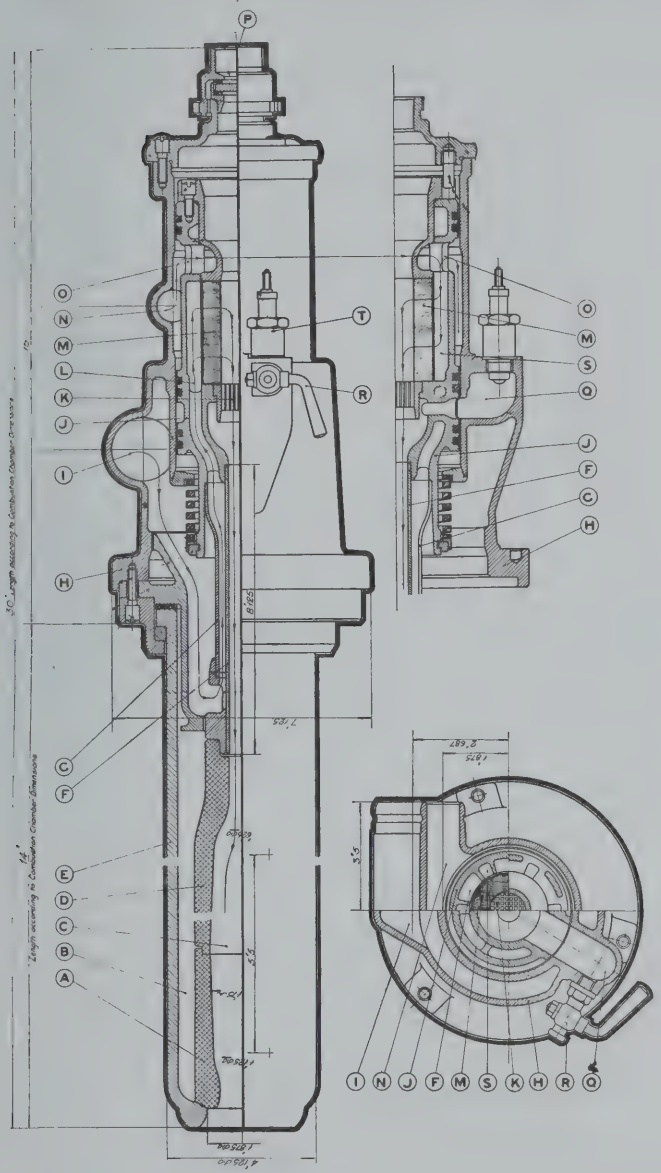


FIG. 12.—*Hammond*, 1926.

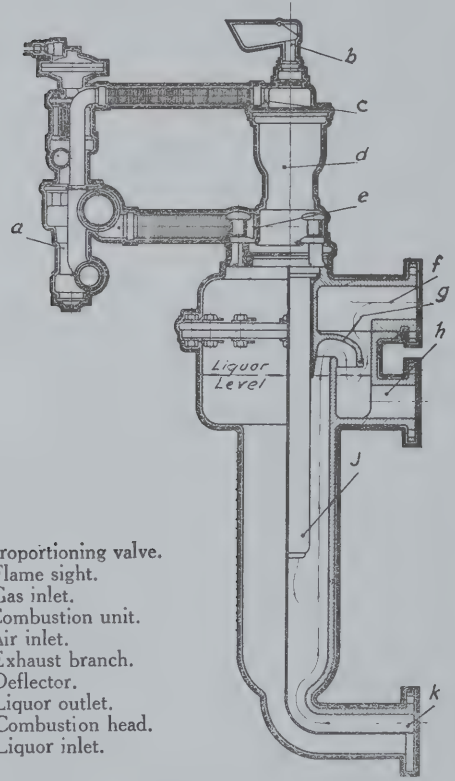
A, Refractory lining. *B*, Packing cavity. *C*, Combustion chamber. *D*, Refractory lining. *E*, Outer casing. *F*, High-velocity tube. *G*, Air-transfer tube. *H*, Main body. *I*, Air inlet. *J*, Mixing chamber. *K*, Meker grid. *L*, Air port. *M*, Mixing pack. *N*, Gas inlet. *O*, Chamber ports. *P*, Flame sight. *Q*, Ignition chamber. *R*, Gas vent cock. *S*, Gas duct. *T*, Sparking plug.

An ingenious attempt to utilise a steam-gas mixture, put forward by J. G. Weir, in 1925, is worth passing attention. According to this scheme, fuel and air are combusted in a chamber into which water is sprayed, producing a steam-gas mixture under a pressure of 500lbs. per sq. inch, and at a temperature of 1,200° F. This mixture (about half steam and half non-condensable gases) is then led to an engine with a back pressure of 50lbs. above atmosphere, and is discharged from it at that pressure, and at a temperature of about 400°, through a low-pressure boiler, in which the temperature is below the condensation temperature of the steam in the mixture. The dried gases then pass to a low-pressure engine. Whatever the value of the method may be for extracting the heat from a steam-gas mixture, the combustion unit for obtaining that mixture was not of a construction suggestive of high efficiency.

An apparatus designed and used by a metallurgical and chemical concern, and for which a patent was granted to S. C. Smith, in 1925, had the merit of giving useful service in practice, in the concentration of chemical solutions and the treatment of ores with hot acid brine. The present writer cannot say what efficiency was obtained from the apparatus as a combustion unit; and in the application in question the fuel efficiency was a consideration secondary to that of improved concentration. Heat efficiency

" approaching 100 per cent." is claimed in the patent specification, but there are no working figures available to support this. The construction of the combustion unit (Fig. 11) embodies an air jacket (*b*), which heats the air for combustion and prevents heat radiation losses from the top part of the chamber, *i.e.*, the unsubmerged portion; and in one form, water-jacketing of the lower part of the combustion chamber was included (*d*). Primary ignition is secured by means of a torch introduced into the combustion chamber. It is interesting to note that practically all the claims embodied in the patent granted for this apparatus, except that for water-jacketing, had been anticipated in some form or other by previous inventors; though it must be admitted that the complete combination showed a distinct advance on most of its predecessors.

Recent developments by Hammond have carried the art of submerged combustion many steps forward, by overcoming the difficulties that restricted the practical application of earlier designs. The construction of a typical Hammond combustion unit is shown in Fig. 12. This comprises mixing chamber, high-velocity passage and combustion chamber. Provision is made for accommodating difference of



a, Proportioning valve.
b, Flame sight.
c, Gas inlet.
d, Combustion unit.
e, Air inlet.
f, Exhaust branch.
g, Deflector.
h, Liquor outlet.
j, Combustion head.
k, Liquor inlet.

FIG. 13.—*Hammond's Circulator Unit.*

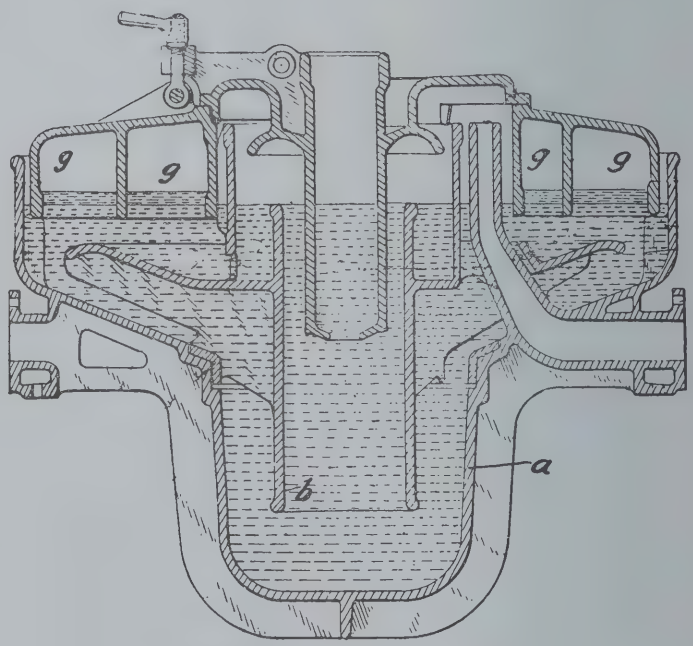


FIG. 14.—*Hammond's Lead Bath Circulator Unit for Caustic Soda Treatment.*

expansion between the outer casing and the refractory combustion chamber, so that the latter is not subjected to disintegrating stresses; while, also, it is surrounded by a cavity that can be packed with conducting material, varying in conductivity according to the use to which the burner is put and the rate of operation. The high-velocity passage between the mixing chamber and the combustion space prevents lighting back, and the upper portion is cooled by circulation of the incoming air. To secure adequate mixing, the air and fuel are passed through a mixing pack in which fine streams impinge on each other, creating the maximum of turbulence and intimacy of mixing. Initial ignition, or lighting up, is by a sparking plug placed as shown, the fuel-air mixture for purposes of ignition being fed through a by-pass, and after the ignition has been effected the flame is carried through the high-velocity tube to the combustion chamber when the proportioning valve controlling the fuel and air supply is turned on to its minimum capacity, after which combustion is confined to the combustion chamber proper. The operation of the

burner can be observed through the flame sight-glass at the top of the unit. Combustion units of the type have been in operation for more than 2,000 working hours without showing any signs of deterioration, although operating under conditions of full pressure and perfect combustion of the fuel. The details of mechanical construction and the efficiency of heat transmission through the combustion chamber walls have a marked bearing on the avoidance of destruction of the refractory lining and the life of the combustion unit generally in submerged combustion systems.

Application of submerged combustion.

Although submerged combustion was first conceived as a means for power-steam raising, it is in other applications that practical developments are likely to first occur, and foremost amongst those is undoubtedly the concentration of liquors in the chemical industry. The external heating of vessels constructed of acid-resisting material is difficult, costly and inefficient; but with a submerged flame the container does not become hotter than its contained fluid and is, therefore, not subjected to destructive influences. Also, the full value of the heat is applied to evaporating the liquid. It will, of course, be appreciated that certain chemicals would be carbonated by the CO_2 in the combustion gases, if subjected direct to the submerged flame; and in such cases elaboration of the appliance to avoid this is necessary. With many solutions the contact with CO_2 is not detrimental, and in such cases the process has the great advantage of evaporation at a reduced temperature, due to the operation of the law of partial pressure producing the effect of evaporating under partial vacuum. Among the liquors which have been successfully treated by means of a submerged flame may be mentioned ammonium chloride, zinc chloride, sulphite-pulp liquor from paper manufacture and phosphoric acid, while sewage sludge also is very amenable to this method of concentration and offers a field for further developments. Experiments on a practical scale, carried out in Germany, showed (according to Brunler) that it was possible to dehydrate sewage from 98 per cent. to about 60 per cent. water content, at the expenditure, per ton of sludge, of 150lbs. of tar oil of 16,900 B.Th.U., the residual material being solid enough to be carted away. In this work, however, the process might with advantage be carried farther, and be rendered self-supporting by utilising the resulting sewage gases as combustibles and the steam for power purposes; while also converting the residue, by complete dehydration, into a valuable fertiliser. The near future will probably show considerable developments in this direction.

Heating systems, either hot water or steam, lend themselves to the use of the submerged flame, as a positive circulation with a very low head can be easily maintained; and coupled with thermostatic control of the combustion rate, a highly efficient heating system is possible.

The use of the circulating lead bath heated by the submerged flame on the Hammond system, opens up a field in oil cracking for the production of motor spirit, by giving readily-regulated heat in direct contact with the oil and at the same time incorporating the efficiency of complete heat utilisation.

Circulation in liquor concentration and other applications.

A valuable feature of the submerged combustion process in liquor concentration and the heating of liquids and possible solids, is the ease with which a circulation of the liquor can be maintained, thus avoiding local heating and incrustation of the container and other parts. One method of effecting the circulation is shown in Fig. 13, which represents a Hammond circulator unit, a feature of which is the function of the flame in operating as the aerating means, as in an air-lift pump. In this circulator the combustion gases are separated and discharged without passing through the body of the liquor. The latter passes from the main container through inlet *k* and rises to the level shown. The combustion unit *d* discharges its hot products of combustion through the combustion nozzle *j*, so that they pass into the fluid, which becomes highly aerated. The aerated column of liquor surrounding the combustion unit becomes reduced in weight and is, therefore, displaced upwardly by the superior weight of the unaerated column in the tank, pan or vat with which the circulator chamber communicates. This upward displacement continues as indicated by the arrow line, so long as the gases from the flame are maintained. The rate of circulation bears a direct relation to the magnitude and temperature of the flame. The deflector *g* throws

the stream back on to the surface of the fluid, causing it to circulate through the liquor outlet *h*, but the gases and any steam or vapour which these gases may carry off pass upwards through the exhaust branch *f*, and are discharged as required. By this means a continuous circulation is maintained from the main container, varying in speed according to the rate of fuel combustion. The unit illustrated is fitted with thermostatic control, and when handling liquids or fusible solids of high boiling point, the temperature may be set below that at which any volatilisation can take place. The effluent from the circulator will then be products of combustion in the form of CO_2 and nitrogen only, and these gases will leave at the temperature of the body of the liquor.

This method of obtaining a steady circulation of heated fluids is not only applicable to liquor concentration and the circulation of water for heating systems, but with some elaboration also affords a means of heating a fluid through the medium of an interposed bath, such as lead, in order to avoid contact with the combustion gases. An example of this is the Hammond apparatus for the concentration and purification of caustic soda and other materials, as shown diagrammatically in Fig. 14.

A layer of the caustic soda to be dehydrated or purified is subjected to the heat of a bath of molten metal, such as lead, on which it floats so as to exclude air, and when the caustic soda becomes anhydrous it fuses and is run off as required. The lead is melted and maintained at the desired temperature by a submerged flame operating in the container *a*, in which the encasing tube *b* is inserted round the burner to produce the circulatory effect, by reason of the combustion gases aerating the molten metal and causing it to rise and flow over the top of *b*. The caustic soda is retained in the chamber *g*, which takes a spiral or circuitous course, so that by regulating the rate of flow, any desired concentration may be obtained. The process is thus made continuous, the caustic soda first being dehydrated and then melted by direct contact with the lead bath, finally flowing out in a continuous stream. In addition to uniformity of heating, the continuous operation of the plant, combined with the highly efficient utilisation of the heat generated, enables a small apparatus to deal with a large output.

It is unnecessary to elaborate further the possible applications for a process which has the distinctive features of submerged combustion. The establishment of the system on a commercially practical basis is too recent for its full possibilities to be realised; but there are many uses in which its potential economies in plant and fuel will be appreciated by engineers and industrialists.

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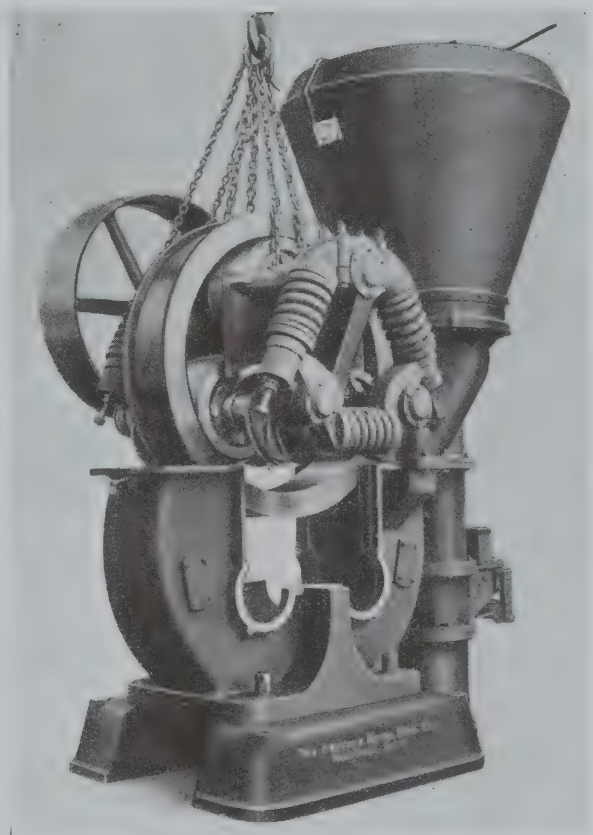
Preparing Fuel for Firing Steam Boilers and Industrial Furnaces by means of Pulverised Fuel.

The use of pulverised fuel for the firing of Steam Boilers and Industrial Furnaces is rapidly extending in this country as the enormous advantages of this method become appreciated. Simple and reliable pulverising plant, capable of operating continuously must, however, be installed if the maximum possible savings are to be secured.

The Ring Roll type of Pulverising Mill running at a slow speed has been proved to be the most durable and reliable in practice where the design is such that the bearings are placed outside the Mill and such vulnerable parts as pendulum spiders, fulcrum levers, sliding bearing holders and screens are eliminated. Wherever Ring Roll Mills embodying these improvements have been installed, their remarkable advantages have resulted in low maintenance costs, reliability in operation and immunity from the serious breakdowns and constant renewals associated with other types of mills.



The Grinding Unit being lifted out of the Mill Housing, illustrating the simplicity of design and quick renewal of Ring and Roller Crushers.

In order to obtain the maximum of economy from the use of powdered fuel, it is essential that the degree of fineness should be capable of being adjusted quickly to suit any variation in the quality of the fuel, and plant should be installed having the widest possible range of grinding, from coarse to superfine.

The fineness of the powdered fuel should be capable of being maintained independently of the wear taking place in the Pulveriser, otherwise the results are likely to be very disappointing after the plant has been in use for some little time. No screens or sieves should be tolerated, as the employment of such devices must result in frequent attention and repairs.

Feeding devices used in conjunction with Pulverisers should be of strong construction and capable of maintaining a regular feed, particularly if direct firing is adopted.

Drying of the fuel may be accomplished inside the grinding system if the plant is suitably designed and a source of hot air is available. The provision of ducts in the walls of the combustion chamber, suitably connected to the grinding system, enables the advantages of air-cooled combustion chamber walls to be obtained, and at the same time provides the source of hot air for drying the fuel inside the grinding system.

Pulverising Plant of simple construction, immune from sudden breakdowns, and remarkably long wearing, embodying all the desirable features outlined above, can only be obtained from

THE BRITISH REMA MANUFACTURING COMPANY LTD.,

PULVERISING PLANT SPECIALISTS,

Hubert Works, HALIFAX.

Telephone 61258-9.

Telegrams: 'DRILL, HALIFAX."

THE CLEANING OF SMALL COAL.

The coal industry to-day is faced with the problem of utilising the maximum proportion of the coal actually mined, and it is no longer permissible to leave behind in the pit such small coal as was discarded in earlier years.

"H.H." Vibrating Screen.

The treatment of such small coal is a specialised branch of fuel technology, and the need for cleaning the smaller sizes is the more pronounced since, in the majority of seams, the small coal contains a higher proportion of ash and dirt than the larger sizes. On this account, special methods of cleaning have been devised, involving the screening, washing, dehydration and possible further drying of the coal. The problem of slurry disposal and the quick return of clean water to the washery is of considerable importance in many collieries treating all sizes of coal, and we offer special equipment for the solution of this problem.

The " H.H." Vibrating Screen is specially suited to the screening of sizes varying from 2 inches down to dust, and as many as four sizes can be produced in one unit by the use of three screen decks. Such a unit is shown in the first illustration. The operation of the screen is extremely simple and very positive, and the machine is particularly free from complicated moving parts, being actuated simply by a high-speed unbalanced pulley firmly fixed to the screen deck. For washing small coal, the " H.H." Concentrating Table is recommended, as shown in our third photograph. This Table is highly efficient, giving results which are practically comparable to " float-and-sink " tests as obtained in the laboratory. The power consumption is low, amounting to only 0.2 to 0.4 H.P. per ton of coal washed, depending on the size of the coal. Any size of coal between $\frac{3}{4}$-inch and 1/16th-inch can be washed on this Table, with better results than can be obtained with any other washing unit.

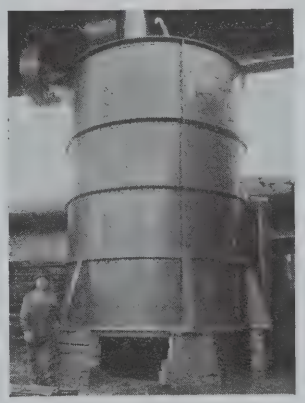
"H.H." De-watering Machine.

After washing, the wet coal is freed from adherent moisture on the " H.H." De-watering Machine, shown in the second illustration. On this machine, the coal, coming from the washing tables with a moisture content of about 40—50 per cent., is subjected to a steady jigging motion over a perforated metal deck of wedge wire, provided with barriers, so that the moisture content is reduced to 8—20 per cent., depending on the size of coal being treated.

If the coal has to be dried still further, as, for example, for use in powdered fuel-fired installations, this can be done by treatment in the " H.H." Vertical Dryer (shown in the fourth illustration) in which

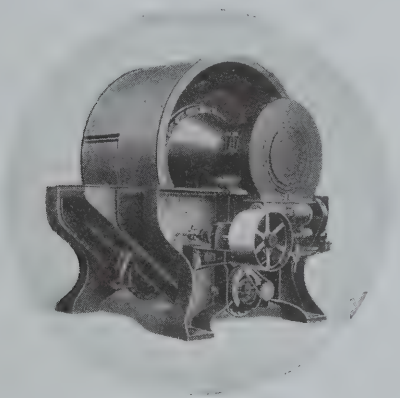
"H.H." Concentrating Table.

it slowly descends through a tortuous path down the cones and shelves of the dryer, meeting in its progress the hot gases coming from a separately-fired furnace or from boiler or furnace flues. The moisture content can be reduced to any desired figure, and rigid guarantees are given regarding fuel and power consumption, capacity and moisture content of the finished coal. This dryer is particularly economical in operation and in upkeep costs, whilst the ground space required is small and the initial cost is low. The loss due to the creation of dust is also lower than with the horizontal type of dryer, due to the great care exercised in the correct adjustment of the air velocity, and a cyclone separator is attached to the dryer to retain any small amount of dust which may be driven off from the dryer.



"H.H." Vertical Dryer

The treatment of slurry water is a problem which must be faced in those collieries which are either short of water or where space for settling ponds is limited, and in this connection the "Wolf" Rotary Filter will be found of great service. The slurry water is fed into a trough, in which revolves a drum, provided with a perforated metal shell, over which is mounted either filter cloth or fine metal gauze. Suction is exerted underneath the perforated metal shell, so that the water is drawn through the fine cloth or gauze and is obtained perfectly clean and ready for re-use in the washery, the fine coal being obtained in the form of a filter cake, containing up to 35 per cent. of moisture, again depending on the size of the particles in suspension in the slurry.



"Wolf" Rotary Filter.

For the filtration of larger sizes of coal, of, say, one-eighth inch size, we also market a flat surface filter, consisting of a rotating table, with a perforated metal deck, covered with gauze, natural drainage being assisted by the suction exerted below the deck.

Full particulars of any of these machines can be obtained by application to :—

HUNTINGTON, HEBERLEIN & COMPANY, LTD.,

47-51, King William Street, LONDON, E.C.4.

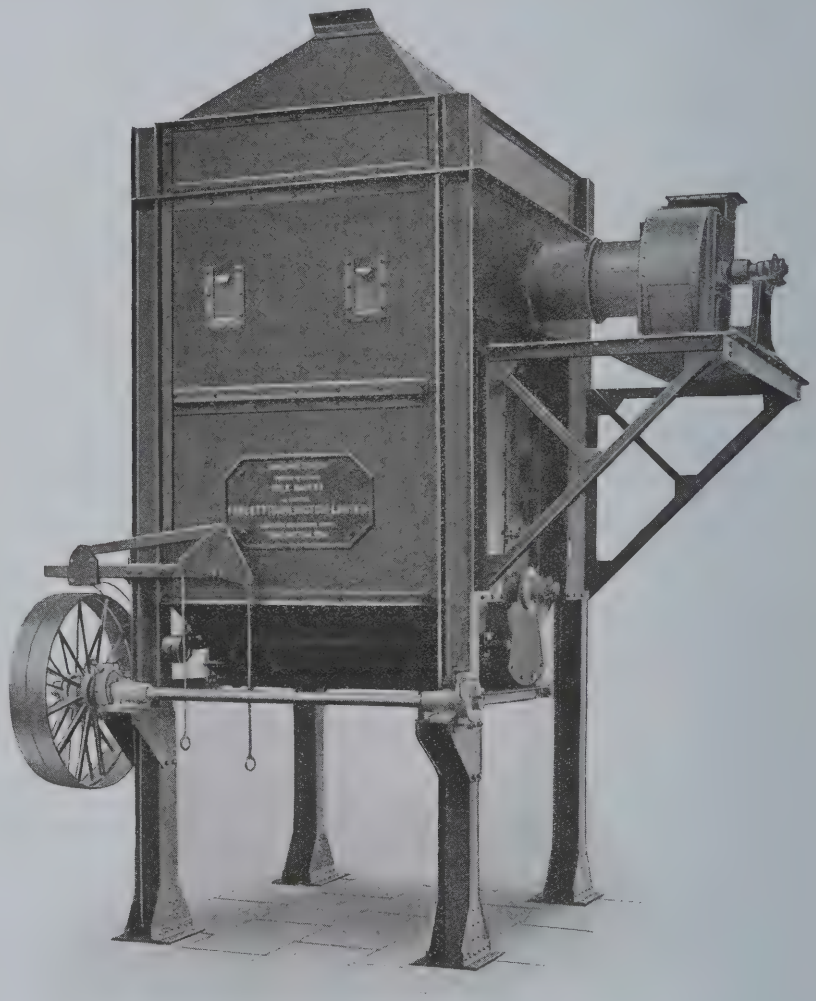
Telegrams: "Innovation, Cannon, London." Telephone: CENTRAL 2415—6.

TAR MACADAM, COAL DRYING AND BRICK-MAKING PLANTS.

The success of a road depends upon the material used in road-making, and, as Tar Macadam is one of the principal materials used, it is essential that manufacturers should endeavour to produce tarred material which will give the best results. To do this, it is necessary that the material should be dry (not hot) before being tarred. By using a "Sangwin Vertical Dryer" you ensure the material being dry by passing large volumes of hot air through the material. Other outstanding features of this Dryer are that the base space is very small, large storage capacity, and the power required is almost negligible, whilst the material dried retains its sharp edges.

Coal Drying.—This Dryer is suitable for drying small coal before being ground, owing to its special construction which no other dryer possesses.

Brick-making Plants.—The success of a Brick-making Plant depends to a large extent on the selection of the right class of machinery to suit the material which it is proposed to make into bricks. Brick earth varies to such an extent that, prior to the installation of any brick-making plant, it is advisable to consult someone with trade experience in order to ascertain which method of manufacture, Stiff-Plastic, Semi-Plastic or Plastic, is the most suited to the material to be dealt with. The two methods first-named make the bricks so hard that they can be set in the kiln without primarily passing through the drying shed.



Dryer arranged for utilising waste gases. Capacity from 5 to 60 tons per hour.

For further particulars and advice write:—

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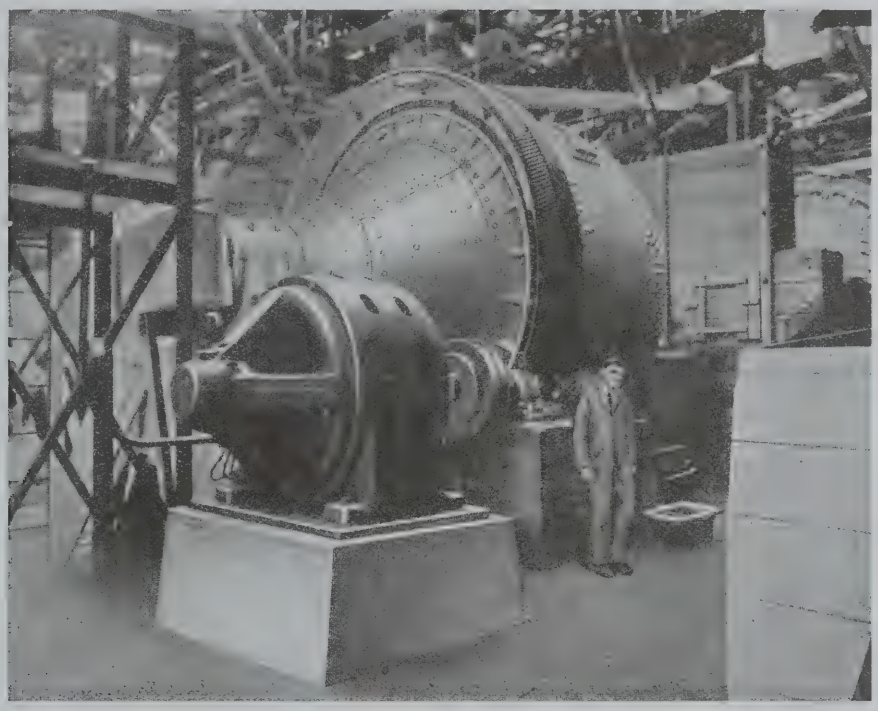
COAL PULVERISING AND STEAM PRODUCTION

This all-important link in the process chain of converting certain raw coals to steam has only comparatively recently received the attention it demands.

The largest individual cost in the process is that of grinding. Hence any saving effected here will have the greatest effect on the ultimate cost of steam production.

It is not the intention in these notes to discuss the relative merits of individual grinding units, but to refer to types of mills, their application, and the lines upon which experiments are being conducted for the general improvement in grinding methods.



The Hardinge Mill.

TYPES OF COAL GRINDING MILLS.

These may be classified roughly into three groups:—

(1) Comparatively high-speed mills, in which grinding takes place by centrifugal force between a fixed metal surface and metal bodies being free to move against or rotate against such surface, such as the Raymond Mill, in which air separation forms an integral part of the unit.

(2) High-speed mills, such as disintegrators, under which heading are included those in which reduction is carried out by impact.

(3) Slow-speed mills, such as the Hardinge, in which the grinding is done by a large number of metal grinding media free to cascade or roll in a slowly rotating drum. Air separation usually forms an integral part of the grinding unit.

APPLICATION.

Type No. 1. The moderately high-speed mill is largely employed in plants in which the central system is adopted, where average grade bituminous coal is used.

The high-speed mill is used on bituminous coals for unit or direct firing.

The slow-speed mill finds its principal application in grinding hard coals with high ash content of coal and coke mixed, and anthracite.

There will be found a certain amount of overlapping in the applications of the mills above referred to, but the main factor in determining the type of mill is the characteristics of the combustible to be ground.

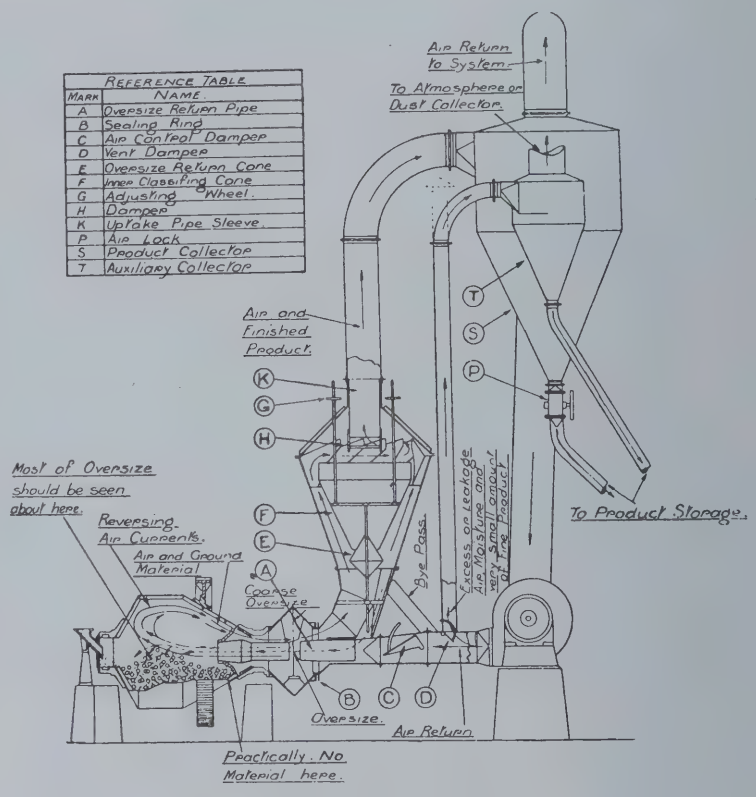
Only a portion of the output of motor or lineshaft driving a grinding unit is utilised in the actual work of reduction; wasted energy is reflected in vibration, noise and friction. The obvious line of attack is to reduce the amount of waste energy. Considerable improvement in this direction has been effected by:—

(1) Attention to design and composition of moving parts.

(2) Adjusting the speed of a mill to a given problem in contradistinction to adopting a set speed for a range of problems.

(3) The design of pipes and bends to reduce friction and to prevent deposits.

(4) The placing of fans behind cyclones, thus eliminating fan wear, and permitting high efficiency fans to be used. This arrangement has the further advantage of placing the unit under a vacuum (except for the return air pipe) rendering the grinding plant clean and dustless by the acid test of full-sized units working under actual conditions.



The Hardinge Air Classifier.

The lines of improvement now under weigh will be briefly indicated:—

Group 1.—An interesting design is in process, in which the body of grinding chamber revolves or gyrates, while contact of the grinding media against the body is induced by centrifugal force. These media are held stationary in one plane, but free to revolve against the grinding chamber, the advantage being that inexpensive grinding media can be employed.

Group 2.—Improvements in air control and return of oversize.

Group 3.—A slow-speed direct-firing unit pulveriser is in process of development in order to convert hitherto useless material, on account of high grinding costs, into useful energy.

Combustible material varies considerably in character both as regards " grindability," abrasiveness and moisture.

Certain coals exceeding 10 per cent. of moisture may be effectively ground without drying; others containing 5 per cent. of moisture would require drying before effective grinding could be carried out.

EFFECT OF MOISTURE ON GRINDING.

It may be stated that the power absorbed in grinding by any means is least when the coal is dry. The critical moisture content in relation to efficient grinding varies somewhat for different types of mills. As a general rule the disintegrator type of mill will handle a damper coal than other types.

POWER ABSORBED IN GRINDING.

Where the specifications to be filled are the same, Type No. 1 uses least power.

MAINTENANCE.

The cost for renewals will always be less per ton pulverised with the slow-speed mill Type No. 3.

Tabulating for Power, Maintenance, Moisture and Fine Grinding below 85 per cent. through 200 for the three types in order of merit, we have:—

	Power.	Maintenance.	H_2O	Below 85 per cent.—200.
(1)	Type 1 ...	... Type 3 ...	... Type 2 ...	... Type 1
(2)	Type 2 ...	... Type 1 ...	... Type 1 ...	... Type 3
(3)	Type 3 ...	... Type 2 ...	... Type 3 ...	... Type 2

The Hummer Screen.

The application of slow-speed mills to coal grinding is important, as certain low-grade coals, anthracite, duff, etc., due to their abrasiveness, were considered worthless owing to the high cost for renewals on the standard grinding equipment then in vogue, but with the introduction of the slow mill maintenance cost is small and the extra power absorbed is relatively unimportant in view of the large saving effected on upkeep. Hence material which a few years ago was unusable is now capable of being transferred into cheap electrical energy.

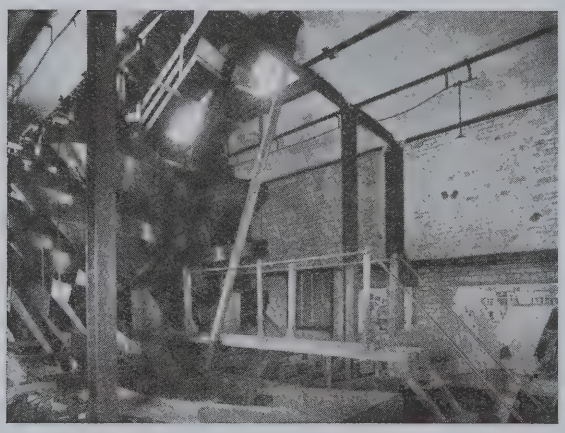
The scope for improvement is immense, but practical advance is only obtained by exhaustive experiment.

INTERNATIONAL COMBUSTION, LTD.
Grinding and Pulverising Dept.,
11, Southampton Row, LONDON, W.1.

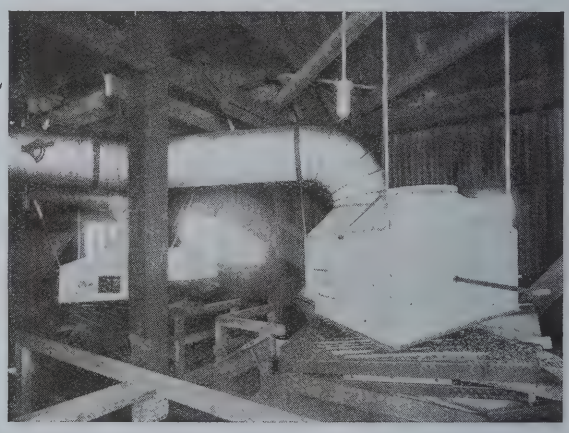
THE DRY CLEANING OF COAL.

The demand for dry clean graded coal is continually increasing. Buyers are prepared to pay more for it than for wet clean coal. Colliery Companies whose coal comes dry from the pit should therefore dry clean it. They, thereby, enhance the price obtainable as well as maintain the demand.

The whole output of a colliery below 4in. in size can be cleaned and accurately graded into marketable sizes by a combination plant of Spiral Separators and Arms Air cleaning tables. The Spiral Separator requires no power to operate, so that running costs are lower than with any other type of cleaner, wet or dry. The power expenditure with Arms tables on sizes below 1in. is low, so that the overall cost of cleaning by a combination plant is a minimum. By examination of a small sample of raw coal, an accurate estimate of the results obtainable can be made. There is nothing experimental about either Spiral Separators or Arms Air cleaning tables, as they are each cleaning over two and a half million tons annually, and new plants are being installed.



A Spiral Separator Plant.



An 'Arms' Air Cleaning Plant.

HUGH WOOD & CO., Ltd.,

NEWCASTLE-ON-TYNE.

SOLID SMOKELESS FUEL AND BLAST-FURNACE COKE.

There is a demand for Solid Smokeless Fuel for use either in central heating or for the domestic grate. Such a fuel must have certain well-known characteristics. It must be readily combustible, easily ignitible, relatively free from moisture, low in ash, and sufficiently compact not to occupy an undue volume as compared with coal. Coal Cleaning and correct Blending of coals are, therefore, essential in the majority of cases, whatever carbonising plant may be employed.

PEALE-DAVIS DRY COAL CLEANING PLANT.

THE WOODALL - DUCKHAM COMPANIES have, for years, made a special study of Coal Cleaning and Blending, and have acquired the rights of the latest American practice in Dry Coal Cleaning for the Peale-Davis System. This process has the advantage that coal from, say, 3-inch to dust is fed on to a table without preliminary screening. The tables are of high capacity, and moisture up to 6 per cent. does not affect the efficient cleaning of the coal.

The Companies are also in a position to supply plants incorporating the principle of Froth Flotation and Jig Washeries.

Where washing is employed, it is essential that the coal sent to the carbonising plant shall be dry. For this purpose the Companies have developed a Centrifugal Dryer, capable of dealing with up to 100 tons per hour.

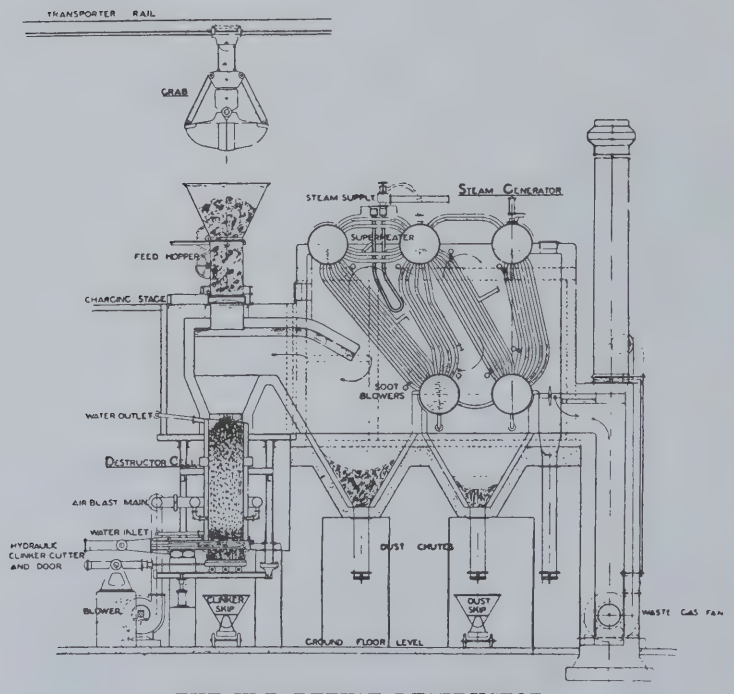
BECKER COKE OVEN.

Subject to the coal being low in ash and dry, the most important consideration from an economic point of view is the type of Coke Oven in which either the Solid Smokeless Fuel or Blast Furnace Coke is to be made, and that oven which can best reduce the overall cost of production of coke is the one which will achieve the greatest economic success. In the Becker Oven, the Companies have a system which has been thoroughly tried out in both the United States and Europe. The Oven

SOLID SMOKELESS FUEL—continued.

can be built in any size and is capable of giving maximum outputs for each particular size. This is rendered possible through the special system of heating and the attainment of even temperatures over the whole of the oven wall.

POWER FROM TOWN'S REFUSE.



THE W-D REFUSE DESTRUCTOR.

In England the cost of Power is controlled by the cost of Coal, and unless other and cheaper fuels are available, coal will be the controlling factor. Town's refuse contains sufficient combustible matter to produce large quantities of electrical energy if scientifically designed Refuse Destructors are installed. The Woodall - Duckham Companies' Refuse Destructor and Power Plant is capable of producing at least 100 kilowatt-hours per ton of Refuse—and there is a ready outlet for the residual clinker.

For further information apply to:—

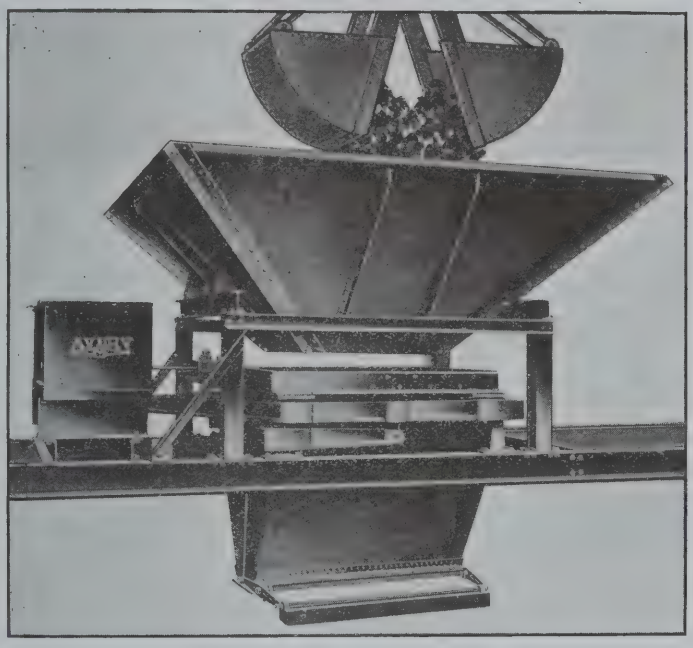
THE

WOODALL-DUCKHAM VERTICAL RETORT AND OVEN CONSTRUCTION CO.

(1920), LIMITED,

- ALLINGTON HOUSE, 136, VICTORIA STREET, LONDON, S.W.1. -

CHECKING COAL CONSUMPTION.



The No. 65 Patent Automatic Hopper Weigher and Totaliser, for Intake.

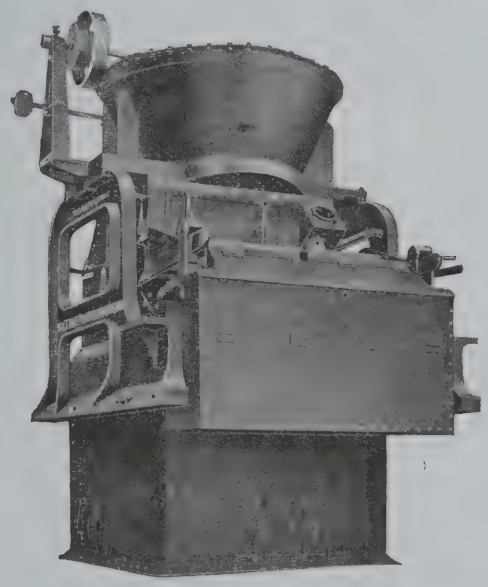
With a view to checking fuel consumption, and as a means of preventing waste, it is important that Boiler Houses should make use of Accurate Automatic Weighing Machines for recording Coal Intake and Coal Consumption.

Accurate Coal Intake.—The Avery Patent Automatic Totalisers give:—

1. The Net Weight of Coal Intake.
2. The Net Weight of Coal automatically recorded and totalled.
3. Accuracy guaranteed.
4. The " Out-turn " indisputable.
5. No tare of trucks, no calculations, no weigh clerk.
6. Machine certified by the Standards Department and stamped by the weights and measures inspector.

Accurate Coal Consumption. — The Avery Patent Improved Automatic Coal Scale installed in your Boiler House is the most efficient and infallible system of recording coal consumption and a sure means of combating waste.

This machine weighs within an accuracy of ½ per cent.



The Avery Patent Automatic Weigher for Pulverised Coal.

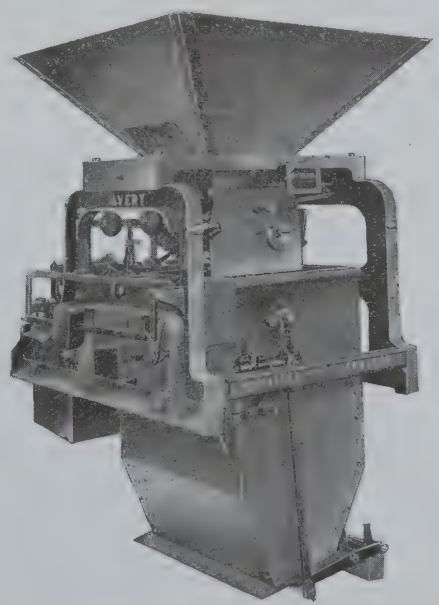
Accurate records of Pulverised Fuel Consumption are given by the Avery Patent Automatic Weigher, without dust escape. The machine shown weighs 50 tons per hour from an overhead storage hopper and delivers to the pump. Accurate records of fuel consumption are automatically kept by the Avery machines and losses instantly detected and economy achieved.

AVERY

FURTHER PARTICULARS FROM .. ..

W. & T. AVERY, LTD.
:: SOHO FOUNDRY ::
BIRMINGHAM.

Ref. No. 828



The No. 48 Patent Automatic Boiler Scale, for Lump Coal.

SUSPENDED FLAT FURNACE ROOFS.

As a means of improving the efficiency of boilers and saving fuel, many devices and appliances have been introduced during the last 25 to 30 years, such as various systems of feed water heaters (economisers), superheaters, mechanical stokers, travelling grates, etc., etc. However, until comparatively recently, but little attention has been paid to rational construction and design of furnace arches or roofs. The sprung arch which has been commonly in use has the following disadvantages:—

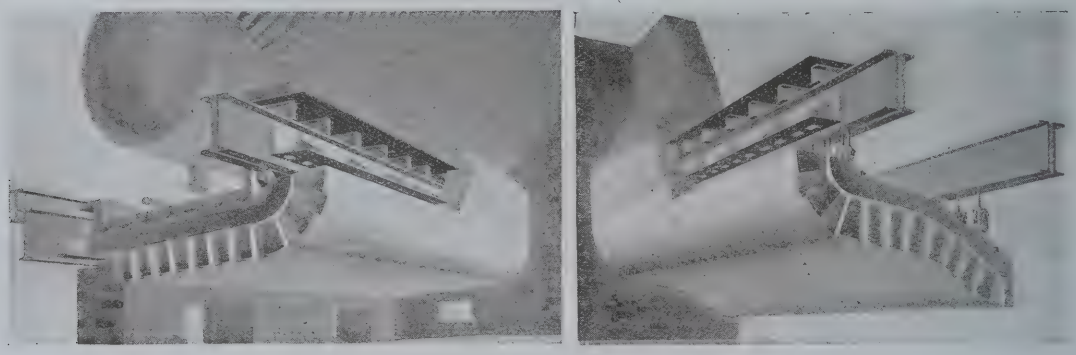
(1) The outward pressure of the arch on the side walls is so great that they must be specially reinforced, and the span of the arch limited.

(2) In two stoker boilers a middle wall to support the arch is necessary. To withstand the severe treatment the wall must be solidly built, and this considerably reduces the available grate space, and causes unavoidable expense in repairs and renewals.

(3) When the temperature in the furnace attains a degree sufficient to cause softening of the refractories, the pressure to which they are subjected in the arch causes them to lose their shape and brings about deterioration and collapse, incurring loss by stoppage of plant and in cost of repairs and renewals.

(4) The arch being a greater distance from the grate at the centre than at the sides cannot radiate the heat evenly over the whole width of the fuel bed, resulting in loss of fuel from imperfect combustion.

These main disadvantages of the sprung arch are still more emphasised owing to the modern practice of working boilers at higher furnace temperatures which has led to the invention and introduction of flat suspended roofs of various systems.



Rear Roof *"Karrena" Flat suspended Roof applied to a Stirling Boiler.* *Front Roof*

The KARRENA suspended flat roof consists of specially shaped blocks suspended between hollow prismatic girders, through which, for the purpose of cooling them, air circulates. The method employed in suspending the blocks from the girders renders it impossible for the blocks to slip or subside. Further advantages of the KARRENA roof are:—

(*a*) The steel and iron parts of the roof are a PERMANENT CONSTRUCTION.

(*b*) No walls are necessary between the grates to support the roof. SAVING IN REFRACTORIES AND LABOUR AND INCREASING THE GRATE SURFACE.

(*c*) The refractories, being suspended, are not subjected to any contact pressure, and have therefore a considerably longer life. INCREASES CAPACITY OF PLANT, SAVES FUEL, REDUCES MAINTENANCE COSTS.

(*d*) The heat is evenly radiated over the whole width of the grate. IMPROVED FUEL COMBUSTION.

(*e*) The shape of the girders and the shape and method of suspension of the blocks permit the designing of the roof with any sweep or curve in its longitudinal section to suit any conditions. ROOF ADAPTABILITY.

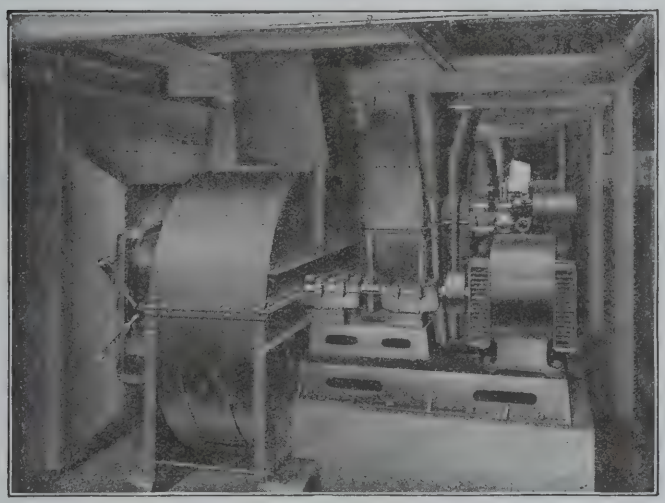
Full information can be obtained on application to:—

A. B. CLEWORTH & CO., LTD.,
118, Queen Victoria Street, LONDON, E.C.4.

MECHANICAL BOILER DRAUGHT.

Mechanical Boiler Draught is essential for economical Steam Production, since it allows the Boiler Plant to work always under the most efficient conditions.

It not only provides adequate draught to enable thicker fires to be used, with consequent greater rate of combustion than is possible with Natural Draught, but also increases the temperature of combustion in the furnace, thereby raising the efficiency of the Boiler Plant.



Sirocco Induced Draught Fans in a London Station.

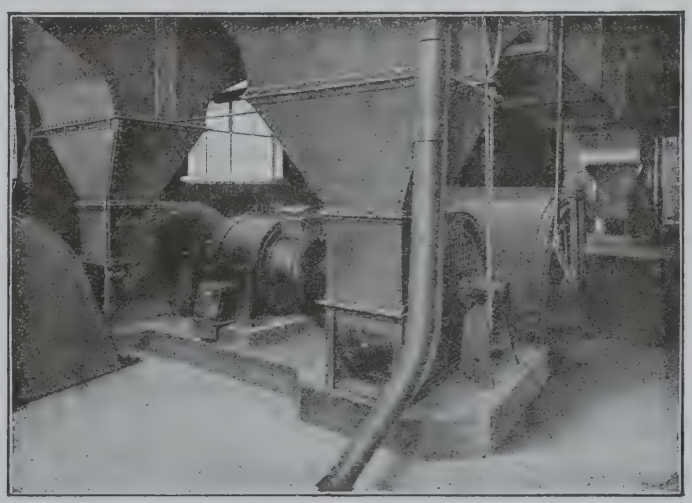
Further, it allows low-grade fuel to be burnt with excellent results, and by ensuring the complete combustion of the fuel eliminates waste due to unburnt coal passing over the dumping bars with the ashes.

The flexibility of Mechanical Boiler Draught makes it possible to adjust the draught power to suit the grade of fuel, and renders the Boiler Plant free of the influence of atmospheric conditions, and capable of meeting sudden demands for steam at all times.

Results obtained with Sirocco Mechanical Boiler Draught have shown what remarkable economies can be secured. Thus, in a Colliery a saving of £260 per annum was effected, in two Textile Mills a saving of 14% and 17½% respectively, while in a Paper Mill the reduction in cost of fuel per ton of paper amounted to 46%.

For full particulars of the Sirocco Mechanical Boiler Draught apply to—

DAVIDSON & CO. LTD.,
Sirocco Engineering Works,
Belfast.



Sirocco Forced Draught Fans in a London Station.

FLUE DUST COLLECTION.

Large Industrial Plants and Electric Power Stations are now burning vast quantities of low-grade fuel having a high ash content, and many Plants are in operation day and night, with the result that a continuous stream of solid matter is emitted from the chimneys into the air.

The desire to abate this nuisance and the fact that in the Davidson Patent Flue Dust Collector there was at length a means available to check effectively the emission of dust from chimneys, has created a rapid demand for these Collectors, and they have been installed in a large number of important Power Stations throughout the World, as well as in numerous industrial concerns.

A Davidson Flue Dust Collector applied to a steel chimney.

There are three types of Davidson Flue Dust Collectors, all of which can be arranged in a variety of ways, so that they can be applied successfully to every kind of Boiler Plant.

Results obtained from the many hundreds of these Collectors that have been installed have proved that they are capable of catching from 0.4% to 13% of the fuel consumed, the quantity of dust depending upon the quality of the fuel and its ash content.

The Collectors, on account of their high efficiency, are invaluable for Power Stations located in residential areas, and for Industrial Concerns requiring a dust-free atmosphere for the manufacture of their products.

For full particulars of the Davidson Patent Flue Dust Collectors apply to—

DAVIDSON & CO., LIMITED,
Sirocco Engineering Works,
Belfast.

FUEL SAVING AND IMPROVED COMBUSTION.

The Eddystone is a patented apparatus which has proved its efficiency in over 4,000 installations. It consists of a centre boss of stream-line form from which project a number of helicoidal vanes of increasing pitch so designed that the draught loss is a negligible quantity. It is manufactured of high quality refractory brickwork, and is installed in the flue of Lancashire and other tank boilers, where it ensures thorough mixing of the gases. As it is in an incandescent state the unburned gases are ignited and thorough combustion takes place. Also the whirling motion imparted to the gases gives these a higher velocity relative to the flue wall and increased heat transfer results therefrom.

COMPARISON OF CONDITIONS WITH AND WITHOUT THE EDDYSTONE.

With the Eddystone.

1. Gases are set in whirling motion, increasing their velocity relative to the tube walls and bringing them into the closest contact with those walls.
2. The temperature of the gases leaving the furnace tube is reduced owing to the increased heat transmission.
3. The increased velocity of the gases as well as their whirling motion carries the grit and soot out of the tube.
4. The absence of deposit allows the boiler to be operated for longer periods without cleaning.
5. The gases are thoroughly mixed and combustion is complete.
6. The brickwork is not overheated and radiation losses are reduced to a minimum.
7. Coal is saved and evaporation is increased.

Boiler fitted WITH Eddystone.

Without the Eddystone.

1. Hot gases are carried along the centre of the tube in parallel streams without coming into contact with the walls. Heat is thus lost.
2. The temperature of the gases leaving the furnace tube is high, due to the low transmission of heat.
3. Grit and soot are deposited in the furnace tube.
4. The deposit of grit, etc., decreases the transmission of heat, making matters worse.
5. The gases are not well mixed and incomplete combustion results, increasing the deposit of soot, etc.
6. The brickwork of the flues becomes overheated, and radiation losses occur.
7. Coal is wasted.

Boiler WITHOUT Eddystone.

EDDYSTONES LTD., CAXTON HOUSE, LONDON, S.W.1.

'PHONES : Vic. 5606 and 2855.

GREEN'S FUEL ECONOMISERS.

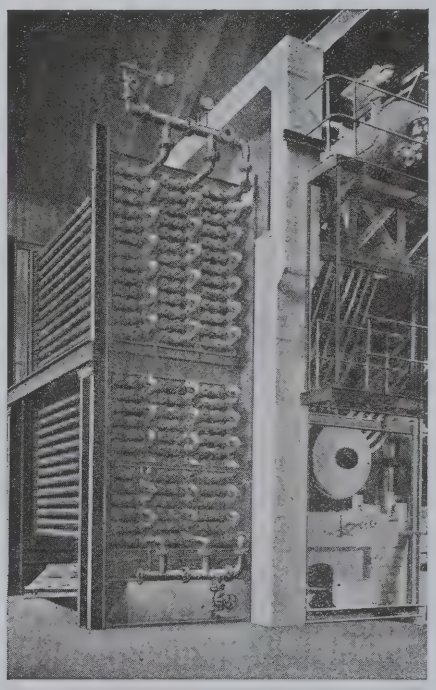
For over eighty years GREEN'S FUEL ECONOMISER has been recognised by steam users in all parts of the world as an indispensable auxiliary to boiler plant. Its function is to supply hot feed for the boilers, not by the consumption of additional fuel, but by the further utilisation of the ordinary supply.

The Economiser is a stack of vertical or horizontal tubes pressed into headers and erected in the path of the hot gases from the boilers. The Economiser tubes and headers, which are full of water, absorb a good proportion of the heat of the gases and the temperature of the water in them is raised as much as 200° F. This hot water is then fed to the boilers.

Hot feed to boilers means less heat required to produce steam, that is, less fuel to be consumed on the boiler grates. This reduction in fuel consumption is often as high as 20 per cent.

For economical steam raising, no boiler plant should be without a Green's Fuel Economiser.

FOR HIGH-PRESSURE PLANTS, E. Green & Son, Ltd., manufacture an Economiser, certain tubes of which are fitted at the header socket joints with "ringstays." This "ringstay joint" consists of an external ringplate and split ring threaded on to the end of the tube. The ring is held firmly to the shoulder of the tube by the ringplate, and this is secured to the header by four set screws. This reinforcement greatly increases the holding power of the tube and header.



Green's Tri-tube Horizontal Economiser at a Power Station

GREEN'S TRI-TUBE HORIZONTAL ECONOMISER, comprising sections containing three tubes each, was originally designed for erection in a horizontal position over modern types of Water-tube Boilers. Its many advantages, however, such as its accessibility for cleaning and its high efficiency, have led to its almost universal adoption in modern high duty, high-pressure boiler plants, and it is installed both above and behind the boiler.

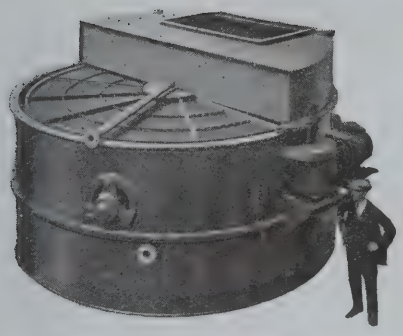
The illustration shows an actual installation at a power station, the Economiser being finally enclosed in steel casing to form, with the boiler, an integral unit.

E. GREEN & SON, LTD., manufacture designs of Economisers to meet every possible Economiser requirement. Both smooth and gilled tubes are supplied.

The special metal of which Green's High-pressure Economisers are made is remarkable for its homogeneity, uniform distribution of graphite and great tensile strength. Economisers made of this metal are capable of withstanding the highest boiler pressures to-day met with.

E. GREEN & SON, Ltd., WAKEFIELD, ENGLAND

Telephone: 443 **Telegrams: "ECONOMISER"**



Air Preheater for boiler evaporating 120,000 lbs./hr.

HIGH BOILER EFFICIENCY DEMANDS AIR PREHEATING.

Preheating the air for combustion by the recovery of the waste heat in the flue gases has been well known for the last half century in special branches of engineering, particularly in marine practice and metallurgical processes, but it is only within recent years that it has been applied extensively to land boiler plants. The reasons for its comparatively recent adoption in this field are two-fold.

Firstly, the introduction of the Howden-Ljungstrom Air Preheater, incorporating the regenerative contraflow principle, has made it possible to effect a very high heat recovery from the waste flue gases at a cost and in a space which compare favourably with that of the older preheaters of the recuperative type capable of only about half the heat recovery.

Secondly, the increasingly common practice of feed water heating by bled steam seriously restricts the usefulness of the economiser, which was formerly the usual means of waste heat recovery, while the increasing boiler pressures now in use tend to make the economiser more costly and less satisfactory.

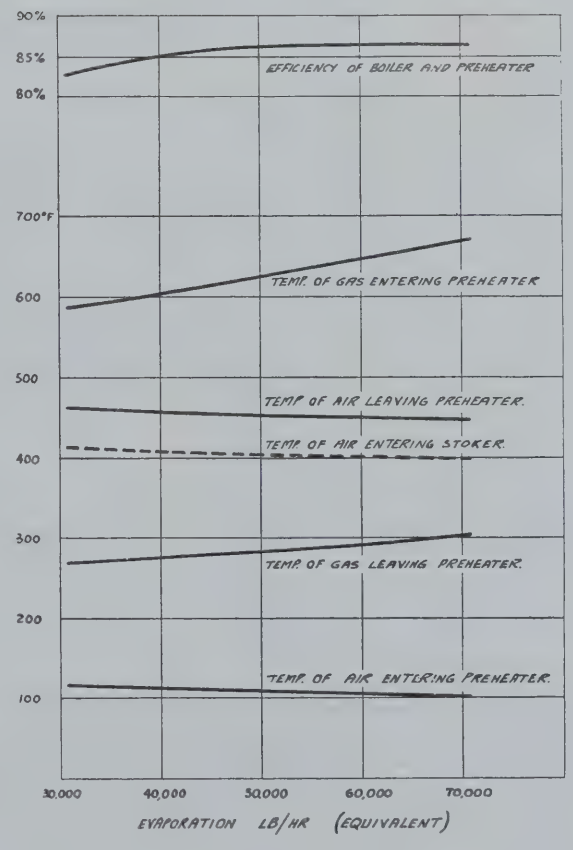
A constant recovery of about 65 per cent. of the available heat in the flue gases for which the standard Howden-Ljungstrom Preheater is designed can be guaranteed over an extended period. This is due, among other reasons, to the fact that *effective* and *positive cleaning* arrangements are incorporated in the preheater, by which the whole heating surface can be thoroughly cleaned while the preheater is in operation in less than one minute.

Owing to the regenerative principle employed in this preheater the temperature of the heating surface is the mean between that of the gas and the air and, consequently, it is safe to use exit gas temperatures lower than those advisable with recuperative heaters. Even should corrosion ultimately occur, the preheater may still be used without any ill effects, as the sealing between the flue gas and air is quite independent of the heating surface.

In addition to the saving effected by the large recovery of the waste heat, the preheated air gives an additional saving by improving the combustion conditions in the furnace and the introduction of the Howden-Ljungstrom preheater has in some industrial plants reduced the fuel bill by over 30 per cent., while overall efficiencies of the boiler unit of 89 per cent. on the gross calorific value of the fuel have been obtained.

The Howden-Ljungstrom Air Preheater was introduced more than seven years ago, and there are now over 550 in operation throughout the world. These are installed in Power Stations and Industrial and Mining Plants, and it is significant that almost 50 per cent. of these preheaters are repeat orders placed after the users had experience of them in operation.

The preheater, which is entirely of British manufacture, can be applied to existing plants as well as to new ones, and descriptive literature will gladly be sent or proposals submitted without obligation by—



Howden-Ljungstrom Preheaters (Land) Ltd.,

Caxton House, Westminster, LONDON, S.W.1.

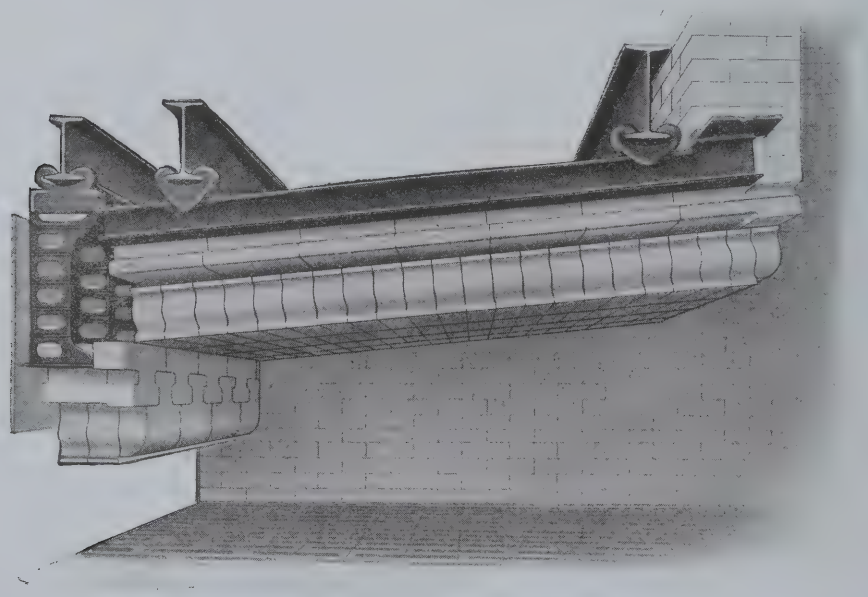
Telegrams: Preheating Parl. *Telephones: Victoria 5606 and 2855.*

SUSPENDED ARCHES FOR FURNACES.

The function of a furnace arch is to radiate heat and reflect it over the whole of the fuel-bed. A curved arch is not ideal for this purpose because its shape is not suitable. A flat arch approaches the ideal, but it is only recently that methods of construction have been found which enable flat arches to be built satisfactorily; so rapidly have their advantages been realised, however, that many flat arches are now in use.

The advantages of a flat arch are (i.) the ease with which a worn-out block can be replaced; (ii.) the uniform distribution of the heat; (iii.) the much greater span available; (iv.) an increase in the volume of the furnace; (v.) a reduction in maintenance costs; (vi.) greatly improved combustion; and (vii.) greater durability of the arch.

The " life " of any arch will depend upon the conditions in the furnace, but in no case do flat arches fail as quickly as sprung arches under the same conditions.

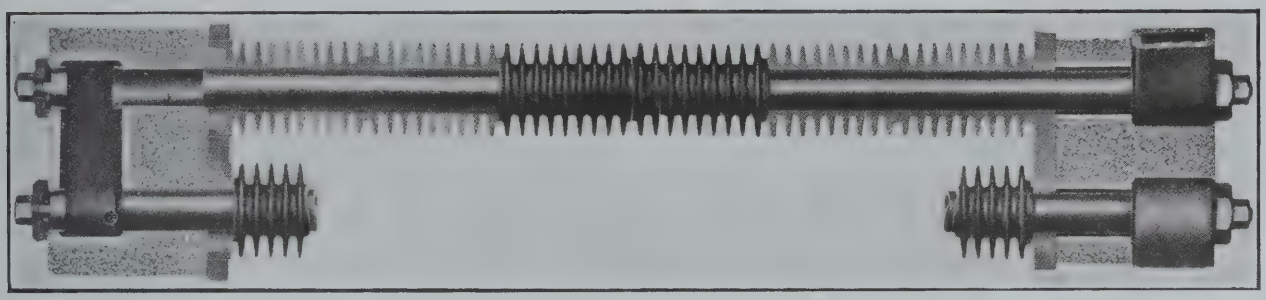


As will be seen from the illustration above, a flat arch is suspended from a series of horizontal girders, which are so fully protected by the refractory blocks, that if the whole of the lower blocks were burned away there would still be refractory protection between the furnace heat and the iron work. Any of these blocks can be replaced in a few minutes.

Flat arches may be either single or double, as required ; they can be adapted readily to special requirements; ignition arches and rear arches can be provided and flat arches can, with advantage, be made to replace existing arches.

LIPTAK FURNACE ARCHES, LTD., 38, Victoria Street, London, S.W.1, are manufacturers of flat arches for all kinds of furnaces.

VITAL PARTS OF A BOILER PLANT.



When considering the design of a new boiler plant there are three very important parts which should receive consideration. These parts act in series and on their proper functioning and correct design depend to a large extent the results obtained. The Economiser—Purifier—Superheater—heat the feed water, dry and clean the steam generated, and then superheat it, each performing its own duty and passing the fluid on to the next.

The essentials of a good Economiser are that it should be strong enough to withstand the boiler pressure plus the possible violent shocks of water hammer; therefore, steel tubes. It must be able to withstand the corrosive action of the waste gases; therefore, cast-iron tubes. It must occupy a minimum of space with maximum accessibility, and the gases and water should flow in opposite directions. All these points are found in the Foster Economiser, a tube of which is illustrated above, and consists of a steel tube on to which are shrunk cast-iron rings.

On the left is an illustration of a Tracy Steam Purifier designed to remove all the impurities and moisture from the steam before it leaves the boiler.

On the right is a photograph of a Foster Radiant Heat Superheater forming part or all of one of the walls of the combustion chamber. The characteristics of this Superheater are such that an almost constant steam temperature is obtained at any rating of the boiler.

POWER SPECIALTY COMPANY LIMITED

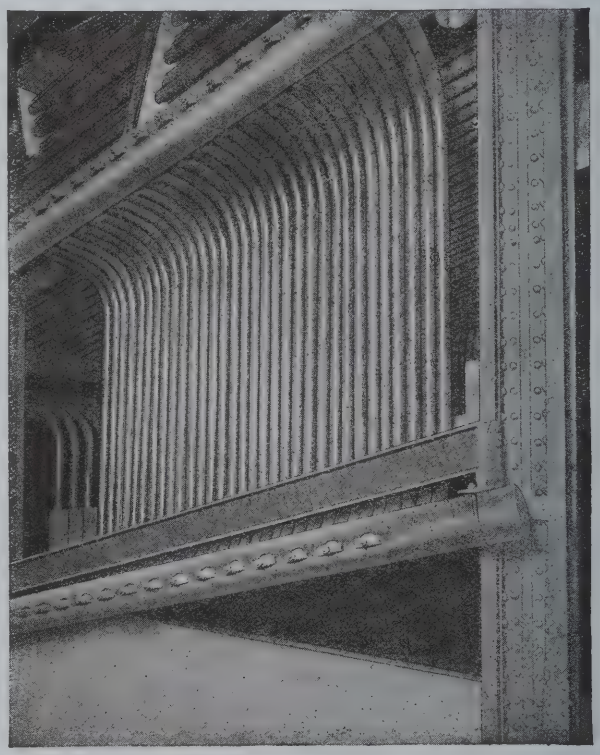
ALDWYCH HOUSE,
ALDWYCH, LONDON, W.C.2.

Water-Cooled Furnace Walls.

In order to secure maximum combustion efficiency and low cost of furnace upkeep, the partial or complete screening of furnace walls by means of water tubes is now being adopted. This striking development in furnace design has not only achieved the purpose for which it was introduced, but has also made possible longer periods of uninterrupted service and a large increase in the rate of evaporation per square foot of heating surface.

The ideal type of water tube for water wall construction should make it possible to install the maximum area of effective heating surface in the space occupied. The complete wall should be simple in construction and accessibility should be a first consideration. Joints and hand-hole fittings should be as few in number as possible.

The bifurcated tube water wall illustrated on this page satisfies the requirements of ideal construction in every respect. The twin tubes are forged together at their ends, by means of a special machine forging process, to form a single outlet, and these twin tubular elements form a continuous wall so that the entire surface exposed to the furnace is cooled by water. At the same time the number of joints and hand-hole fittings is reduced to a minimum and simplicity in construction achieved.



"M.F.S." Bifurcated Tube Water Wall.

Information and advice regarding the "M.L.S." Bifurcated Tube Water Wall and "M.L.S." Patent Superheaters for Stationary Boilers may be obtained from—

The SUPERHEATER COMPANY LIMITED

Head Office: **195, STRAND, W.C.2.** *Works:* **TRAFFORD PARK, MANCHESTER.**

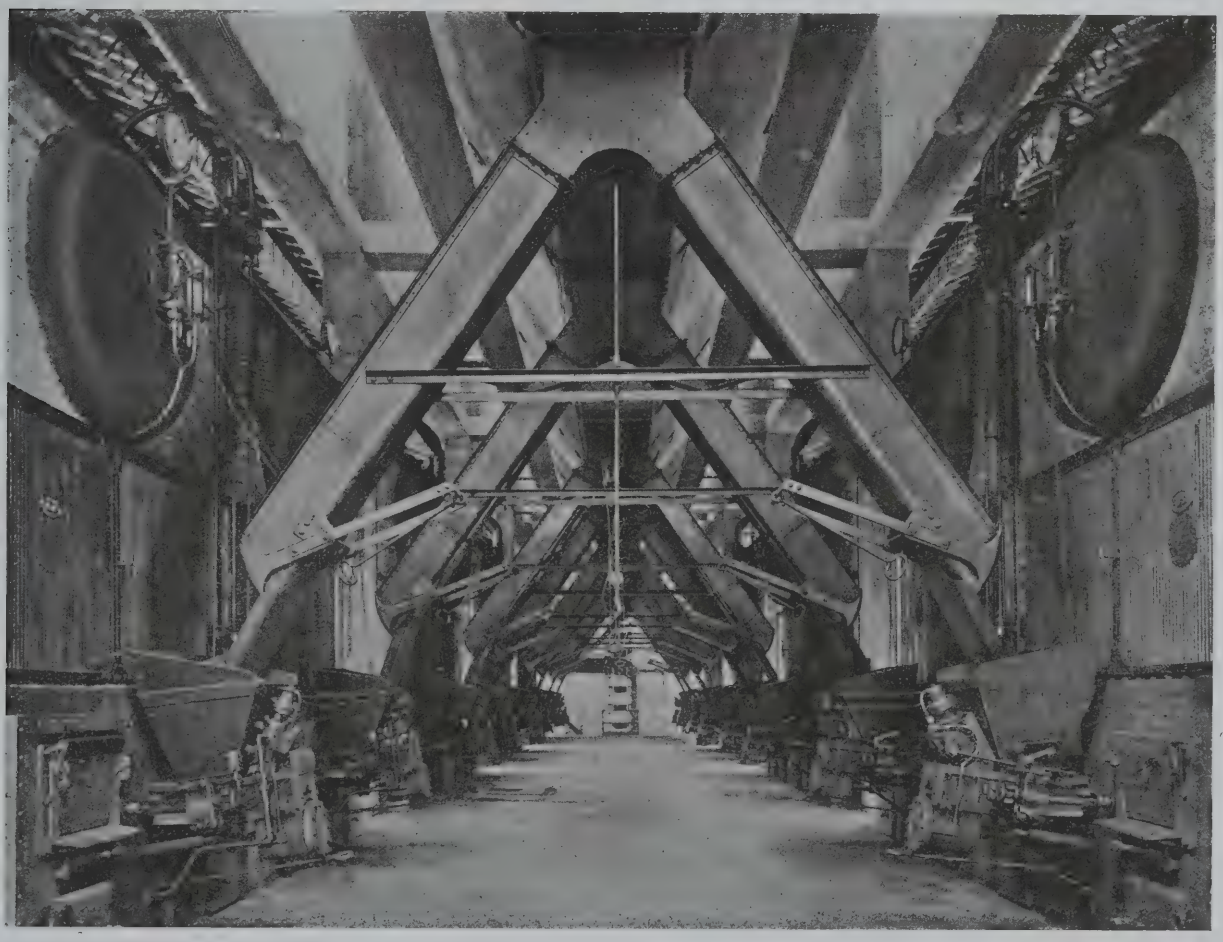
BOILER PLANT EQUIPMENT AND EFFICIENCY.

It is a well-known fact that modern users of steam are constantly demanding higher economies and consequently lower costs in steam production. The present-day boiler house is simply an up-to-date factory for the economic production of a useful article; in this case, steam.

The largest item in the cost of power production is, undoubtedly, the coal bill, and it is necessary, therefore, to design a combustion chamber which, together with the correct type of firing equipment, will enable the complete unit to develop its output with a maximum of efficiency.

The operating conditions of the whole plant need to be considered to ensure that the right type of equipment is installed and the load factor, banking, light and overload periods, should be carefully studied.

The various stoker manufacturers and combustion engineers generally have taken these points into consideration, and there is no doubt that the equipment now being installed is becoming increasingly efficient and has a greater capacity for the utilisation of a wide range of fuels, including certain extremely low grades, hitherto regarded as almost worthless for use in steam production.



Group of Boilers equipped with Class "E" Underfeed Stokers.

One of the first companies to realise the importance of economic fuel consumption from the consumer's and the national point of view, was the Underfeed Stoker Company, Ltd., who, some twenty-five years ago, put their class "B" stoker on the market. This stoker was primarily designed for use

in internally-fired boilers, and is still much used for Lancashire boilers. The machine in question is of the Underfeed type, the fresh fuel for the maintenance of combustion being constantly supplied, by a worm feeder, from below the level of the fire, and gradually advanced upwards towards the combustion zone by a simple and practical mechanism. The method of feeding the fuel to the furnace is just the reverse of hand-firing, where the fresh fuel is thrown direct upon the top of the fire. The green coal falling suddenly upon an incandescent mass of fuel discharges combustible gases rapidly and thus imperfect combustion takes place, and smoke passes up the chimney, resulting in a great loss of economy, in addition to the smoke nuisance. When the fire has again burned bright, it soon becomes necessary to repeat the operation, and so the fires are alternately hot and clear, cold and smoky.

The above inefficient method of firing is duplicated in many mechanically-fed furnaces, and there is no doubt that for such boilers or furnaces as those mentioned, the underfeed method is as rational as overfeeding is irrational.

With the relegation of the internally-fired boiler to comparatively small installations, and the adoption of the water-tube type, it was found necessary to design a stoker capable of meeting the new demands, and the underfeed principle was again found to be sound under the more arduous conditions. Higher ratings were required and the Underfeed Stoker Company, Ltd., designed their class "E" Underfeed stoker. This machine, which is suitable for boilers or furnaces having a width of twelve feet, is first a feeder, and a thorough coker, then it distributes the fuel perfectly and is self-cleaning. The principal advantages of the stoker are :—

1. Greater economy and higher boiler efficiency with a given coal. This is especially the case with variable loads for, regardless of changes in the load or the capacity of the boiler, the grate surface is always kept well covered with coal.
2. Ability to burn a wider range of fuels.
3. Flexibility or ability to meet sudden demands for steam and changes in the load.
4. No necessity for high chimney.
5. Less space in front of boilers.
6. Self-dumping clinker plates.
7. Stoker can be examined and repaired without necessity of removing it from the furnace.

It is, of course, well known that the Underfeed system described in the foregoing invariably employs mechanical draught equipment, thus obviating high and expensive chimneys.

The class "E" stoker was for a great many years the most efficient machine on the market, but as demands for higher capacities and greater economies in fuel consumption were encountered, it was found necessary to design a stoker which would meet the new conditions. Boiler units were becoming larger and, in many cases, boiler ratings were increasing. The larger boilers were made up of heating surface arranged on a small floor space, and the travelling grate stoker solved the problem of the provision of increased grate area in the same furnace width.

The class "A" travelling grate stoker was the pioneer in this country of the forced draught type of machine. The machine is essentially a carrier bar stoker, consisting of an endless moving grate, in which the grate surface, composed of caps fitted with loose self-cleaning inset pieces or fingers, is mounted on transverse bars, which in turn are securely fastened to the driving chains. The chains are driven through the agency of sprocket wheels through a driving mechanism, having eight speeds, a patent clutch and a safety link.

These stokers are made in two types:—

(*a*) Machines where the forced draught is supplied by a separate fan situated in the boiler house or room adjacent, or, as in many cases, in the boiler-house basement.

(*b*) Machines of the self-contained type, in which the fan and driving motor are incorporated in the stoker design, being actually mounted on the front of the stoker coal hopper. In this type of stoker the fan motor is fitted on the coal hopper, being used also to drive the stoker itself.

With the subsequent developments in the boiler house and the increasingly high ratings and efficiencies demanded, a still more efficient type of stoker has been designed, which is known as the Underfeed class "L" machine.

This machine has been developed to meet the demand for a stoker which can be made in such a size that only one machine is necessary for each boiler instead of two, three or four separate machines, having division walls between them in the furnace. The type "L" stoker can be made in single units up to 520 sq. ft. grate area.

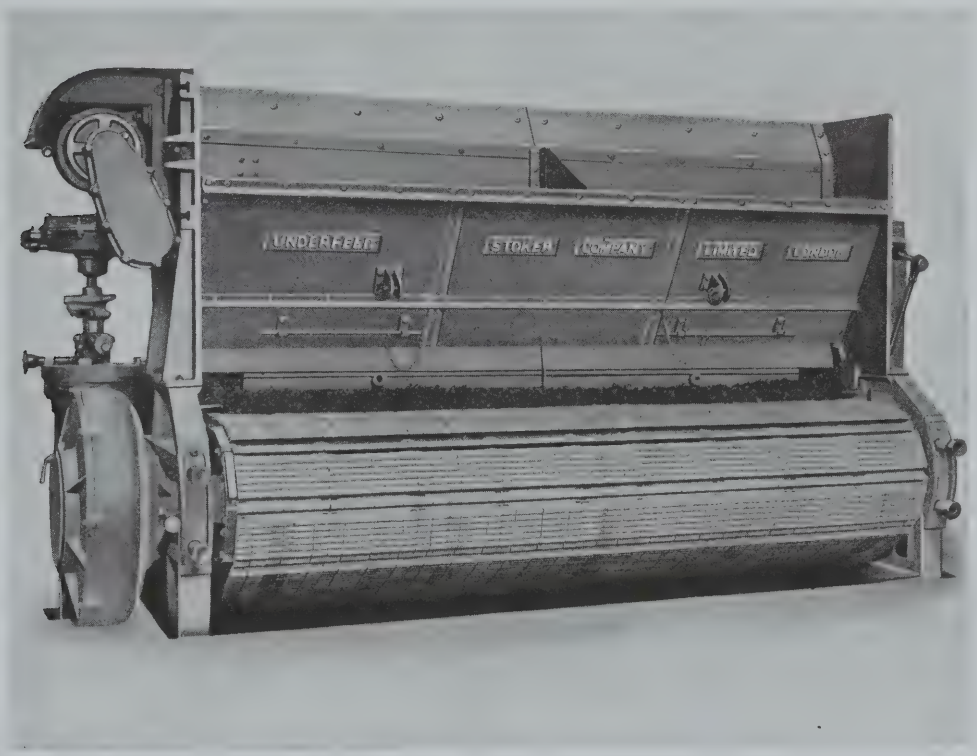
The two most important features of any travelling grate stoker are:—

(1). The construction of the grate surface.

(2). The method of air distribution.

The grate surface employed on the type "L" stoker represents a great advance in design as regards durability, tendency to make riddlings, and resistance to adhesion of clinker which, in many forms of grate, tend to clog the air spaces.

Referring to the attached illustrations showing sectional views of the grate, it should be explained that the grate bars are arranged transversely. They are supported at their ends on steel tension chains which occur at frequent intervals across the width of the stoker, and are sloped downwards in the direction of travel, lying upon each other in the direction of louvres. The bottom edges of the bars are turned



The "L" Type of Travelling Grate.

upwards to form troughs into which fall the riddlings which find their way through the air spaces between the bars. The steel tension chains or carrier chains are spaced equally by means of the rods having pipe ferrules threaded upon them, and the grate is carried on its journey through the furnace on rollers which are threaded on to the transverse tie rods and run upon skids of very large area. As the grate passes around the rear drum, the firebars over-balance on the pivots which are cast on their ends, as shown on the illustration attached, and so empty the riddlings from the troughs, at the same time cleaning the grate surface of any clinker adhering thereto.

The following advantages are claimed for the grate surface:—

(1). The grate is non-riddling. The actual quantity of dust which is deposited inside the main air chamber, measured over a period of months, averages one pound for each ton of coal burnt

on the stoker. This quantity is so small as to eliminate the necessity for any mechanical means for removing the dust from the air chamber. It is quite sufficient if the air chamber is cleaned out once per week and this can be accomplished by raking from the access doors, by a vacuum cleaner, by compressed air or steam pipes blowing the dust towards the rear end of the stoker, from which point it can be ejected through grids arranged in the bottom of the air chamber; or in any other known manner.

(2). The grate is self-cleaning, due to the relative movement between individual members of the grate as they pass around the rear drum. This increases the life of the grate surface, owing to the air space being kept free from clinker.

(3). Any part of the grate surface may be renewed without shutting down the boiler and without disconnecting the tension chains. This operation is best accomplished as the grate is passing around the front drum.

(4). Owing to the angular disposition of the grate bars, the thickness of each bar is considerably less than the pitch of the bars, measured in the direction of travel, and on this account considerable growth may occur on the surface of the bars without fear of reducing the widths of the air spaces.

(5). Due to the "trailing" progression of the grate bars, the possibility of jamming, due to the grate fouling stationary objects such as clinker dams, etc., is reduced to a minimum.

(6). Those parts of the moving chain which are subjected to stress are completely shielded from the heat of the fire.

(7). Should one firebar become broken and fall out of position, the space is immediately filled by the preceding bars falling forward and closing the gap.

(8). The whole grate is flexible, and, therefore, less liable to suffer severe damage in the event of any jam taking place.

Referring to the second important point, on air distribution, this is also quite a novel feature of the type "L" stoker. Instead of distributing air from side air supply boxes built into the furnace side walls and communicating with separate transverse air compartments, the air is admitted into a large air chamber or reservoir which extends the full width and length of the stoker, the height of this air chamber being approximately 2ft. In order to distribute this air to the various combustion zones in the length of the stoker, valves are arranged immediately below the grate. The arrangement of the valves is shown on the two illustrations attached, and the valves in each row are operated simultaneously and independently of all the other rows. There are no divisions in the main air chamber. The advantages of the construction are as follow:—

(1). The volume of the main air chamber is sufficiently large to allow the air to dissipate its velocity, and, therefore, the pressure over the width of the stoker is uniform.

(2). Combustion is under perfect control, and different combinations of air valve settings may be obtained for the purpose of dealing with different qualities of fuel without the need for any change in the stoker itself. The amount of air passing to each zone of the furnace may be controlled with precision.

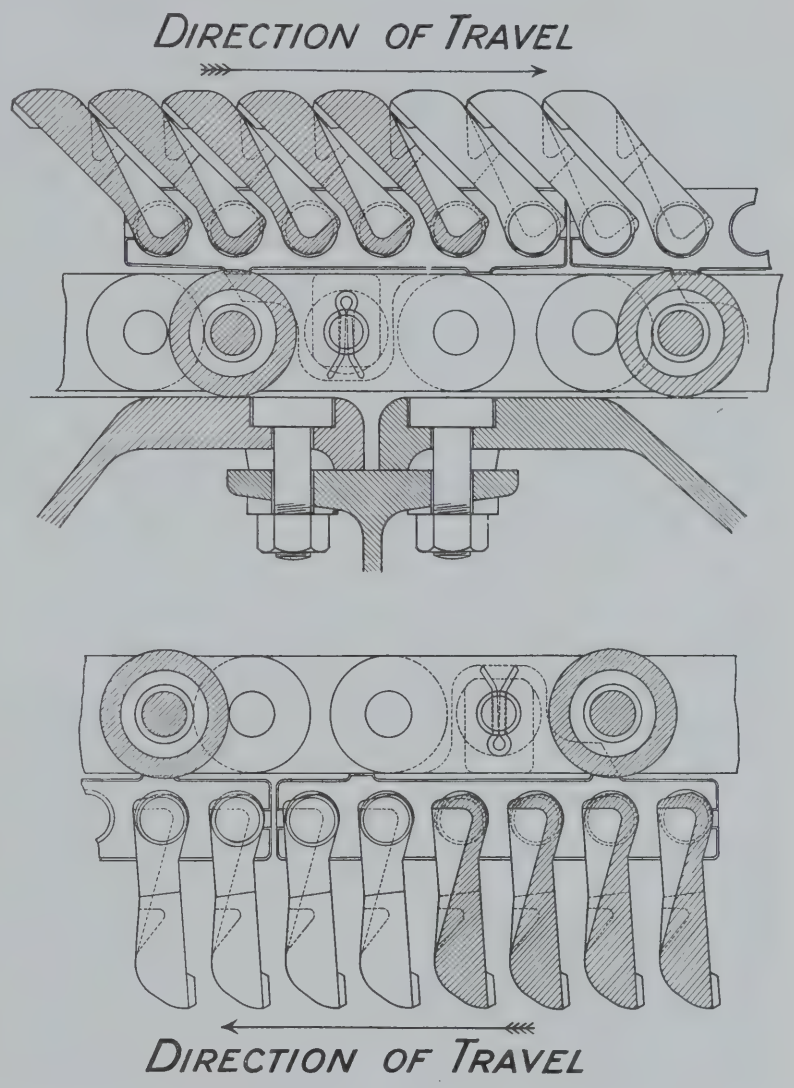
(3). The whole of the framework of the stoker is kept cool in all circumstances by the movement of air. Even if the rear air valves are completely closed so that no air is passing through the grate, the air is all the time circulating and thus preventing overheating of the machine.

(4). The interior of the stoker is completely accessible. Large doors are arranged through the furnace side walls, giving access to the main air chamber and from the main air chamber access may be gained to the whole of the return chains and the front sprockets. All the air control valves and their mechanism are immediately accessible from the inside of the main air chamber.

Type "L" stokers in widths up to and including 13ft. 9ins., are made in the form of single grates but machines exceeding this width have their grates divided in the middle, the space between the adjacent grates being 8ins. This space inside the furnace is filled by an air-cooled cast-iron dead plate and no brickwork is necessary. Each half of the stoker is driven separately and controlled separately, so that in the event of half of the grate going out of commission the boiler may be kept steaming on to the other

half until a further unit can be brought up on the line. It is claimed for the twin grate that it has all the advantages of the single wide grate and also of the double grate.

The type "L" stoker may be driven in a manner similar to the standard "A" type stoker, that is, by means of a line shaft operated from a motor and worm reduction gear, or it may be driven by a motor and gear supported directly on the coal hopper side plate. In the case of the twin stoker, two self-contained gears are necessary—one for each half of the grate. The self-contained gear is recommended in all cases where electric current is available, as by this means it is possible to avoid all shafting, brackets, bolts, etc., which are objectionable in a boiler house. Apart from this, each driving gear is independent of the other, so that in the event of one going out of commission the other gears are not affected.



Louvre Grate. Sectional views showing formation of air passages and self-cleaning action of grate bars.

With the development of the travelling grate stoker, with its ability to utilise low-grade fuels, having a high ash content, the problem of cheap and efficient ash removal arises, and in this connection the Underfeed Stoker Company, Ltd., have evolved four distinct systems:—

(*a.*) *The "Usco" Chain Conveyor.*

This conveyor consists of a horizontal cast-iron or concrete trough, situated below the rear of the stokers, filled with water to give an effectual air seal, and containing a specially designed chain scraper for removal of the ashes. The ends of the chutes through which the ash is delivered to the trough, are sealed in the water-filled trough. This essential feature of a continuous ash-removal plant is thus absolutely assured.

There is no accumulation of ash and clinker, the conveyor being continuous. No sudden loads are imposed on the conveyor, and the power required for operation is thereby reduced to an absolute minimum. The conveyor may be arranged to elevate the ash on inclines up to twenty degrees and deliver to storage bunkers arranged for discharging into railway trucks or carts.

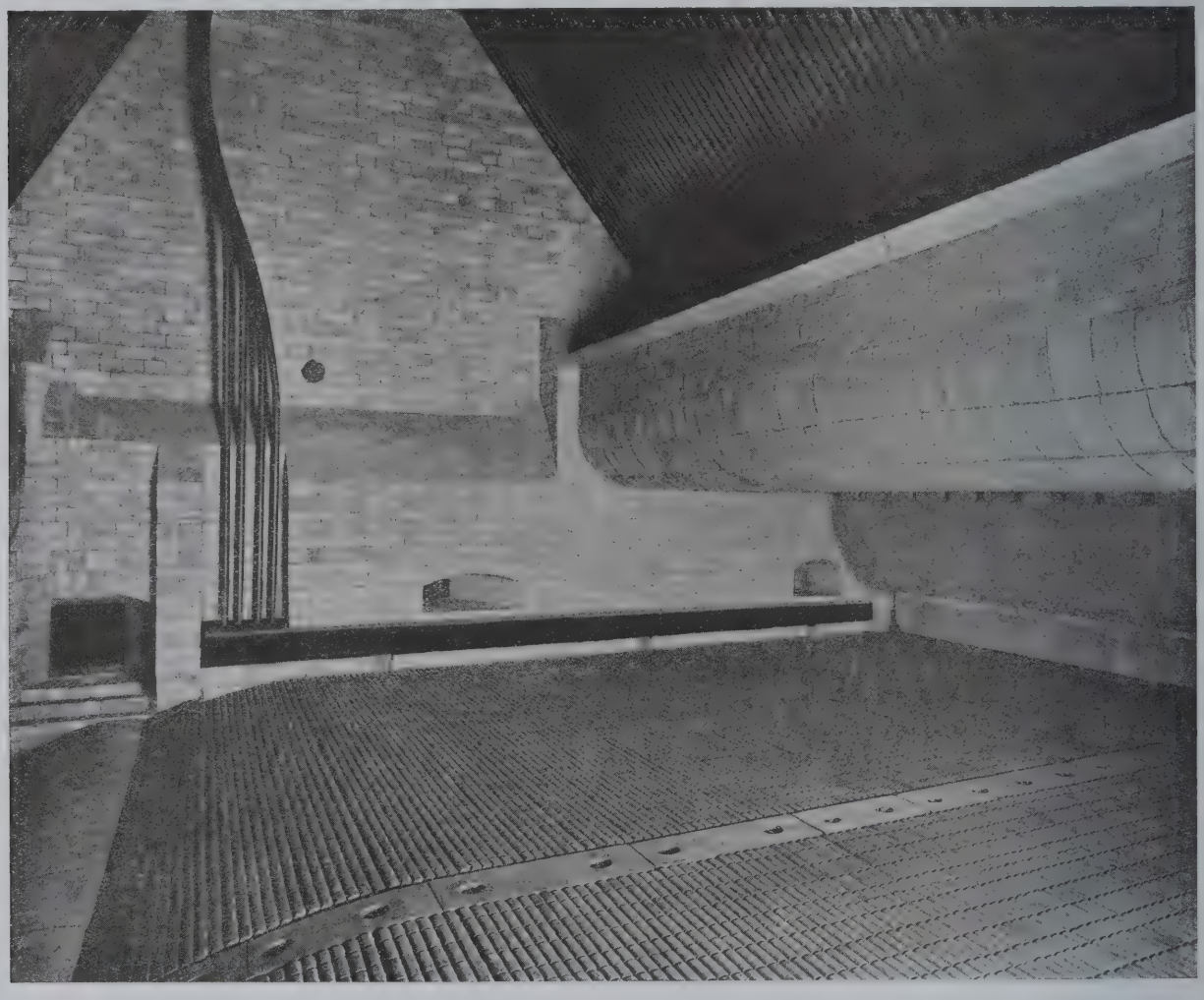
(*b.*) *The "Usco" Sluicing Conveyor.*

This conveyor has been designed to quench and convey the ash as it leaves the grate and to provide the necessary air seal. The conveyor is simply an inclined trough below the rear of the grates, down which flows a stream of water; the ash from the grates falls directly into the trough and is carried away

by the water to a settling pit beyond the boiler house, from which it is grabbed and deposited where required, or alternatively it may be elevated directly into a storage hopper for subsequent removal.

(c.) *The "Usco" Hydraulic Type Ash Conveyor.*

A further development of the sluicing type plant described is the "Usco" Hydraulic Type Ash Conveyor, in which system the sluicing trough under the rear of the grates delivers the mixture

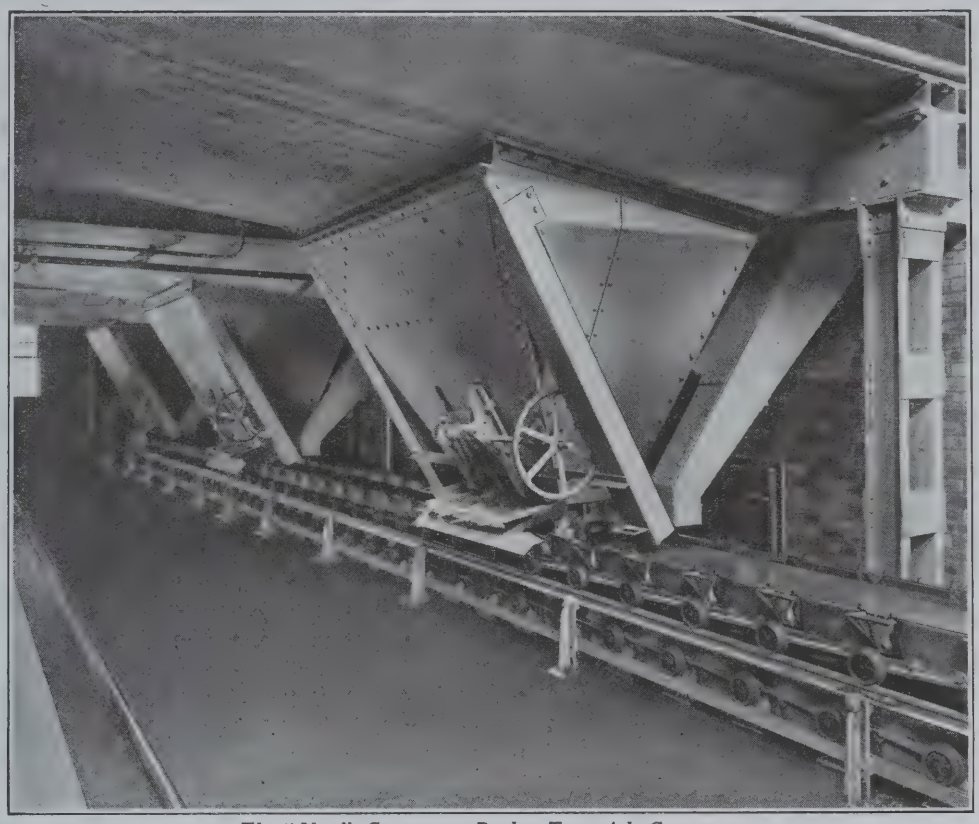


Type "L" Twin Travelling Grate. View showing interior of furnace with Detrick "Usco" suspended arch.

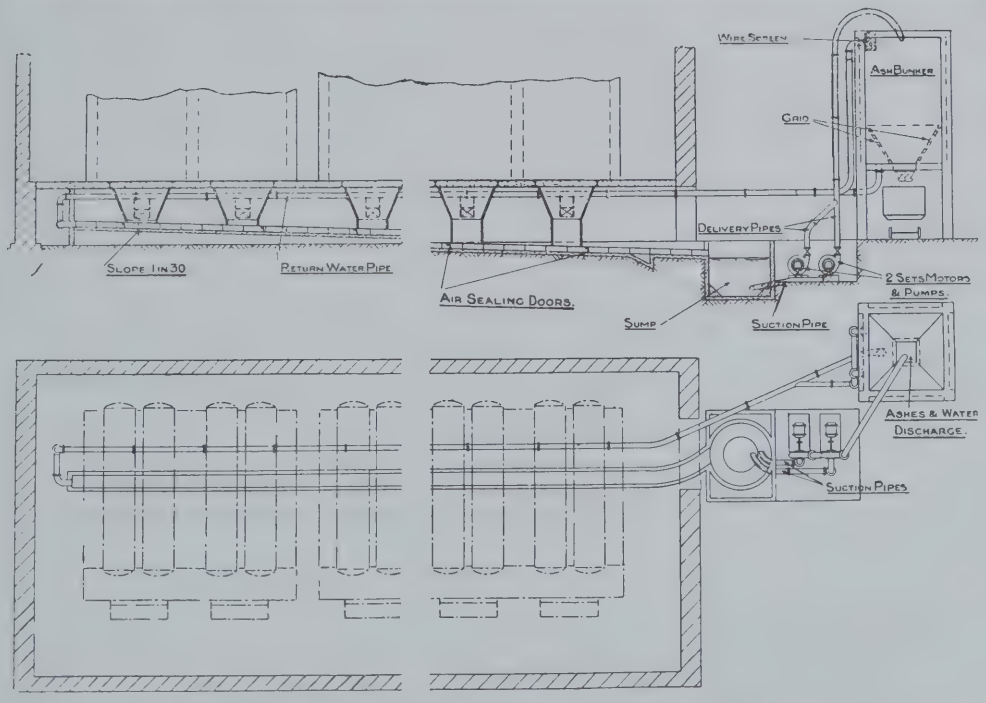
of ash and water to specially designed pumps. These pumps deliver the water and ash to a storage hopper at a convenient point. The hopper is fitted with a patent grid designed to retain the ash and clinker, and the water is then led again by gravity to the sluicing trough. This system obviates the necessity for installing elevating plant for delivering the ash and clinker to the storage hopper, and the cost of operation is extremely low.

(d.) *The "Usco" Continuous Bucket Type Conveyor.*

This type of conveyor consists of a trough made up of pressed steel buckets having rubber joints. The buckets are filled with water, forming a water seal for the chutes from the rear of the grates, arranged in a similar manner to that described in the "Usco" Chain Conveyor. The buckets are attached to a chain supported on a steel track, the chain being taken over specially designed sprocket wheels. The buckets are arranged to elevate the ash to any convenient point outside the boiler house, the ash being deposited in a storage bunker as in the case of the Standard Chain Type.



The "Usco" Continuous Bucket Type Ash Conveyor.



Sectional View of "Usco" Hydraulic Ash Conveyor.

The "Usco" Air Heater. The illustration shows a group of Heater Leaves or Elements in an "Uptake" Connecting Boiler or Economiser Outlet to Chimney.

The adoption of the class " L " stoker has necessitated the use of flat suspended furnace arches, the use of which has been advocated by the Underfeed Stoker Company, Ltd., for a number of years. The attainment of the ideal furnace roof has been the problem to which furnace builders and operators have devoted themselves for years, and to which the Detrick-Usco Flat Suspended Arch most nearly approaches.

Essentially the Detrick-Usco Arch comprises centre grooved tiles which are suspended by means of cast-iron bars from steel beams which span the furnace. The actual work of installing a Detrick-Usco Arch is simple, requiring few operations and may be executed without highly skilled labour. Repairs which may become necessary in course of time may be readily made.

In addition to the economies which may be effected by the efficient combustion of fuel, it is now fully recognised that great savings may be effected by the recovery of heat which would otherwise be lost to the chimney. The " Usco " air heater is an extremely simple and efficient plant, whereby this waste heat may be recovered and returned as useful heat to the furnace. Economies of from 5 per cent. to 30 per cent. may be obtained, and the use of preheated air permits the use of extremely low-grade fuels, having high ash and moisture contents. The heater consists essentially of an aggregation of steel plate elements or leaves, each leaf being a hollow narrow steel box. The air to be heated passes through the box, and the flue gas passes through the space between the elements in the opposite direction to that taken by the air. The elements are electrically welded by a special process, and there is no possibility of the air and gas intermixing. The heater may be fitted in the back of the boiler or in any convenient position in the flue gas ducts.

The design is such that the gas and air take practically straight paths, the resistance thus being reduced to an absolute minimum. Maintenance of the heater is absolutely negligible, there being no moving parts, and low resistance offered by the smooth surfaces of the plates practically obviates the possibility of soot deposit.

These heaters are extensively used in connection with the latest boiler plants, offering a simple and efficient heat economiser at low initial cost.

The Underfeed Stoker Company, Ltd., are also manufacturers of the Impelled Draught Furnace Front, which may be applied to Lancashire and other types of boiler, where the user desires to retain hand firing. These fronts are extensively used in conjunction with the " Usco " Plate Type Heater, and economies of as much as 29 per cent. have been effected in Lancashire boiler installations.

For storing and reclaiming coal, the Beaumont Cable Drag Scraper System is recommended as the best solution of the coal storage problem. Of the many systems in use, consisting of cranes, conveyors, trestles, etc., no other has so many advantages, either mechanical or financial.

The Cable Drag Scraper is a means of storing a large pile of coal on a piece of ground and reclaiming it with the same equipment.

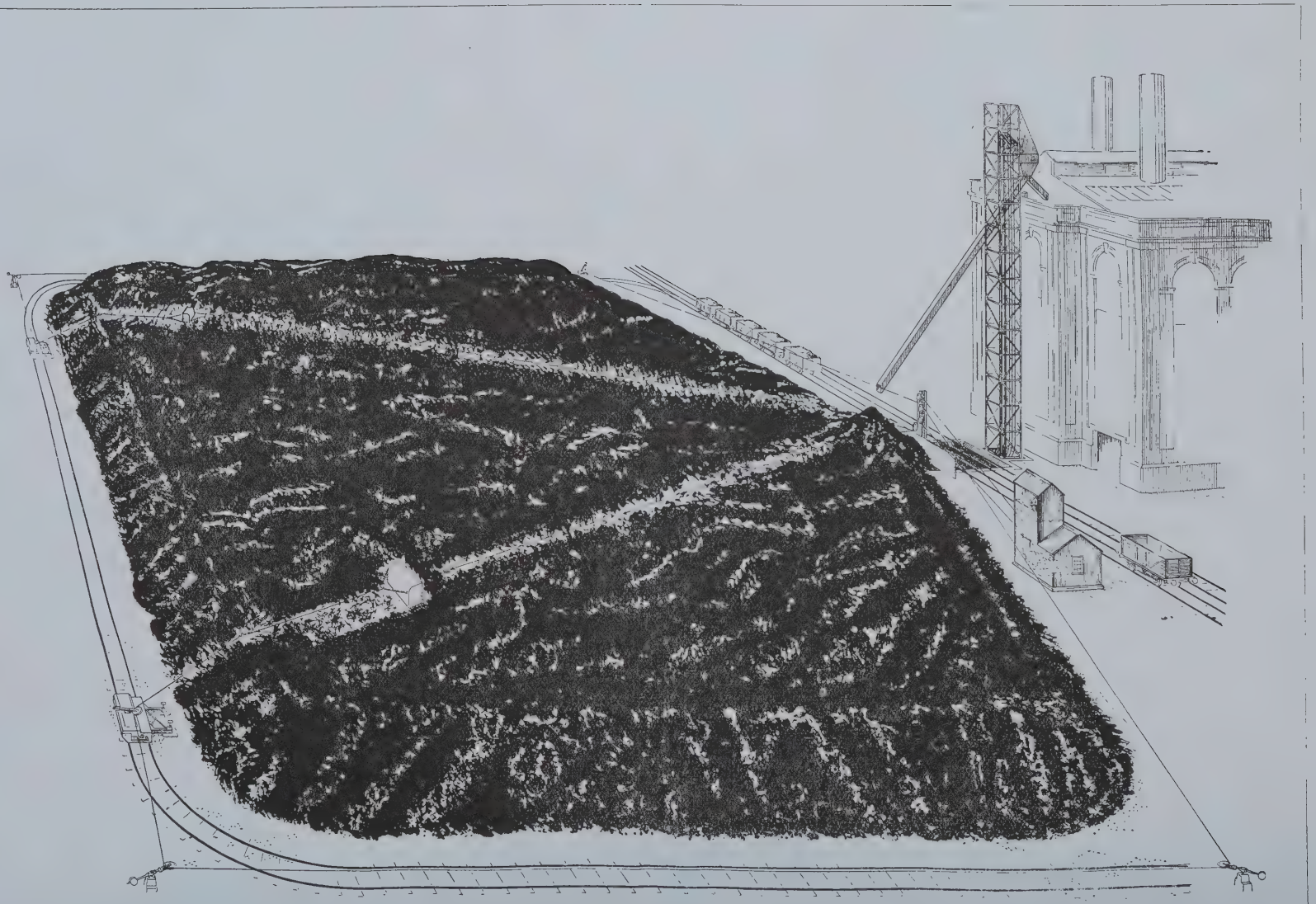
In storing coal, it is first elevated and delivered to a chute to form an initial pile. A machinery house contains the driving drums, to which are attached the ends of a steel cable extending over the storage yard and having the scraper attached to it. The scraper is dragged back and forth over the coal, it being quickly detachable, so that it can be turned around to reclaim the coal. Around the edge of the yard are steel posts. To store coal at any portion of the storage yard, the tail blocks are changed from one back post to another.

In larger installations, the Tail Block Car is used to carry the tail blocks. Running on tracks it can readily be moved to any section of the storage area desired. This eliminates the necessity of moving the tail blocks from one back post to another.

When reclaiming coal, the scraper is reversed on the cable and the coal is scraped back to the reclaiming hopper and delivered to the skip hoist, which will deliver the coal to railroad cars.

The operation of reclaiming is identical with the storage operation, except that the scraper is reversed. The system either stores or reclaims without any changes or additions other than reversing the scraper.

The bigger the installation the more adapted the Cable Drag Scraper. The greater the tonnage to be handled the more logical the use of the Cable Drag Scraper. The greater the hourly capacity the more reason for the Cable Drag Scraper.



The Beaumont Cable Drag Scraper for Coal Storage.

It is the only device that embodies all the essential features of coal storage with many distinctive features of its own.

Other products of the Underfeed Stoker Company, Ltd., are:—

The class "H" Stoker which has been designed to equip furnaces for the following purposes:—Sheet and pair furnaces; general forging, light and heavy; drop forgings; annealing furnaces, axle furnaces, etc. Many of these stokers have been supplied in this country, and the following advantages are claimed:—(1) Saving on fuel bills, (2) increased output, (3) fewer culls or imperfect forgings, (4) reduction in slag, (5) prolonged life of furnace.

Multiple Retort Stokers.

"Usco" Draught Indicators.

CO_2 Thermoscope. A handy portable instrument by which samples of flue gases may be taken and the CO_2 content ascertained.

Beaumont Skip Hoist for bulk materials.

Simplex Automatic Loader for skip buckets.

Beaumont Automatic Train Car for use with a skip hoist.

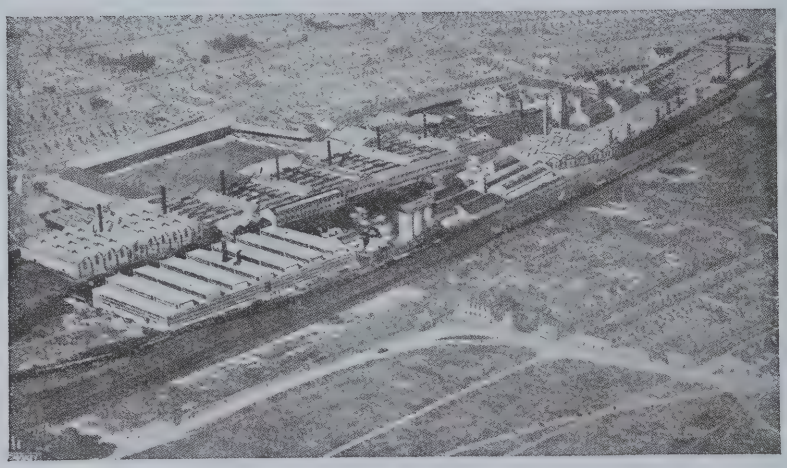
Beaumont Weigh Larries, which dispense with heavy overhead bunkers, chutes, etc., in the boiler house.

Hoppers and gates for coal, ashes, sand, etc.

Steel Hoppers, etc.

"Usco" Unit Pulverisers.

PULVERISED FUEL SYSTEMS.



Aerial view of a large malleable iron works, equipped throughout with Fraser and Chalmers' Holbeck Pulverising Plant.

The necessity for economy in coal consumption and the efficient utilisation of low-grade coals and waste dust, constitute a problem of national importance, and one of the most remarkable developments in steam boiler practice is the increasing use of pulverised fuel firing in power stations and large industrial plants.

The many advantages of pulverised fuel for steam and metallurgical furnaces are now generally recognised, and its extensive application in the United States and by large industrial concerns in this country, affords convincing proof that it is a sound commercial proposition.

In addition to increasing the efficiency of a boiler or furnace, a pulverising plant enables low-grade or refuse fuel to be used, thereby decreasing production costs and promoting industrial economy. It also solves the smoke difficulty.

As fuel plays an important and expensive part in the manufacture of the majority of products it should be burnt efficiently, old methods of combustion being discarded wherever they are admittedly wasteful.

A pulverised fuel plant represents a proved method of obtaining cheaper production, and complete combustion of coal of practically any quality can be effected, providing an efficient type of pulverising equipment is adopted.

Fraser & Chalmers' Engineering Works, which is one of the pioneer firms manufacturing pulverised fuel plants, are manufacturers of the Holbeck system of pulverised fuel firing and also the F. & C. unit system.

Fraser & Chalmers' Engineering Works have successfully applied pulverised fuel firing to water-tube boilers, Lancashire boilers, and various types of metallurgical furnaces in this country.

Economy of Pulverised Coal Firing.

The Fraser & Chalmers' systems of pulverised coal firing enable the heat value of the coal to be utilised with higher efficiency due to:—

(1) Reduction in excess of combustion air, and, therefore, a decreased amount of heat in the flue gases.
(2) Almost complete elimination of unburnt fuel.
(3) Quick and easy regulation of coal and air to suit the load.
(4) Elimination of banking losses.

In addition to higher efficiency of heat utilisation, cheaper coal can be used for pulverising, the saving in the coal bill amounting to as much as 50% in some cases.

The labour saving would also represent a considerable item, as the pulverised coal is distributed through a pipe-line in the same way as gas. The coal storage may, therefore, be situated conveniently for the reception of the incoming fuel, and need not be near the furnace or boilers.

In the case of a works covering a large area, and with furnaces situated at various places, this represents the elimination of considerable expense for coal distribution.

FRASER & CHALMERS ENGINEERING WORKS

PROPRIETORS THE GENERAL ELECTRIC CO LTD

ERITH, KENT.

LONDON OFFICE: MAGNET HOUSE, KINGSWAY, W.C.2.

PULVERISED FUEL THE SOLUTION OF COAL WASTAGE.

Exterior View of Boiler House, Derby Electricity Power Station.

PULVERISED FUEL THE SOLUTION OF COAL WASTAGE.

Since economic conditions have had the effect of increasing the cost of coal, emphasis has been laid on the necessity of raising more coal from the mine than has hitherto been the case. Royal Commissions have revealed the fact that a very large tonnage of utilisable coal has been left in the mine, due to the practice of discarding everything below a certain size. A large proportion of this discarded coal is of good quality, though a considerable quantity contains a high percentage of ash. This ash content could be reduced by the process of dry screening, which, however, would add to its cost and thus place it on practically the same cost level as coal now marketed.

It is clear, therefore, that either this unraised coal must be submitted to methods of combustion which will enable it to give as high efficiency as the coal ordinarily burned, or that it must be supplied at a figure which will level its value up, per B.Th.U., with the latter. The former is at the moment the only course to adopt, inasmuch as by pulverising the material it can be made to yield efficiencies equal to the bituminous coal raised and marketed. There are, undoubtedly, several million tons of this discarded coal which could be utilised in this manner.

The most profitable place to use such material is obviously at the collieries where the cost of steam raising is now far too high. In industrial plants and electric generating stations, in proximity to the collieries also, such material could be used with great financial advantage. This question of nearness to the source of supply is essential, unless the material is treated prior to use for taking off the by-products.

In view of the fact that the average efficiency in colliery boiler plants is no higher than 65 per cent., by the use of the coal now lost in mining this figure could be raised to certainly 83 per cent. or higher, thus reducing not only the extent of the plant employed, but the fuel bill and labour costs. With this form of firing also combustion efficiency is sensibly independent of the amount of, or chemical characteristics of, the ash in the coal, and is, therefore, eminently adapted to burning this low-grade material. There is practically no limit to the character of the fuel utilisable in this system. Every description of coal can be employed irrespective of ash and volatile content, though as regards coals very low in the latter, such as anthracite and coke breeze, there are certain limitations.

In America, it has been found possible to use coal containing from 30 to 35 per cent. of ash, though conditions must determine whether it is a paying proposition to pulverise fuel of this description. In that country, also, anthracite culm from the washery plants is dried and pulverised and forms the only fuel used under power-house boilers which are running on normal loads at between 70 and 80 per cent. efficiency.

Another relevant point is that no account need be taken of size in this system, for, as the whole of the fuel is passed through a grinding mill, the original size of the coal is immaterial, whether it be in the form of dust or small. The varying mass is brought into uniformity by passing it through the mill. With other forms of firing the size of the coal must be up to a certain gauge. It is thus made possible, with this system of firing, to rectify the low value in B.Th.U.'s in a coal by securing more perfect combustion, for it is obvious that the smaller the surface exposed to flame temperature, the more rapid and the more efficient will be combustion. These points have been corroborated in pulverised fuel practice in America, on the Continent, and in this country over a period of eleven years, that is from 1915 to 1926.

Not only, however, is the question of to-day one of utilising coal now wasted because of its high ash content and grade, but that of burning coal of any quality in such a manner that the highest efficiency is obtained. The average efficiency secured from the steam-raising plants of this country is probably not more than from 50-55 per cent. If we could transform into practice the theoretical heat value of coal and make full use of it, the losses incurred in ordinary practice would be removed, and coal consumption per ton of products would be very greatly reduced.

The remedy for this state of affairs lies in two directions, namely, the change in the condition of the fuel and the substitution of a plant by which complete combustion can be obtained. Beyond this, again, is another important consideration, namely, the utilisation of the coal now remaining practically unused for industrial purposes. This is making a great demand on the plant required, and only recent years have shown that such a system of burning coal is commercially available. There can be little doubt,

however, that by effecting these essential operations, we should find ourselves a good way forward in the rehabilitation, not only of the mining industry, but of industry generally.

THE NOW WELL-TRIED AND PROVED METHODS OF OBTAINING THE DESIRED END IS THE ADOPTION OF THE " LOPULCO " PULVERISED FUEL SYSTEM, FOR IF WE CANNOT PURCHASE COAL AT A LOW PRICE, WE MUST REDUCE THE COST, BY EXTRACTING FROM THE MINERAL THE GREATEST AMOUNT OF HEAT UNITS, IN THE MOST ECONOMICAL MANNER. SIR ARTHUR DUCKHAM HAS POINTED OUT THAT WELL BELOW TEN PER CENT. OF THE POTENTIAL ENERGY OF COAL IS TRANSLATED INTO USEFUL WORK. THIS IS AN OMINOUS ADMISSION AND ONE WHICH THE COAL RESOURCES OF THIS COUNTRY CANNOT ENDURE FOR LONG. IF ALL COAL, HOWEVER, WERE PULVERISED BEFORE BURNING, SO THAT THE COMBUSTIBLE PARTICLES WERE SUBMITTED TO THE REQUISITE TEMPERATURE, THIS PROPORTION WOULD BE VERY CONSIDERABLY AUGMENTED.

Interior View of Boiler House Derby Electricity Power Station.

Principles of pulverised fuel.

It is a scientific principle that uniformity ensures greater efficiency, and it is on this principle that the practice of pulverised fuel firing is based. Whether this uniformity occurs in a chemical form, or in a mechanical, the results are always towards more economic and more efficient working. In pulverised fuel the advantages are in the latter category, the surfaces of the fuel being so small, and the cubic measurement being so restricted, that the release of heat is immediate, and its diffusion on a large scale secured. The recognition of these principles is not recent, for the pulverisation of material has been adopted in other industries prior to its adaptation to the firing of boiler furnaces.

It is, therefore, evident, judging only from the main principles and advantages of pulverised fuel practice, that this method is a very valuable contribution to fuel economy in its widest sense.

Economics of pulverised fuel.

The economies resulting from the use of pulverised fuel are not only the ability to attain and maintain a high efficiency of combustion, but also to reduce the cost of labour in the operation of the boilers. One man can handle the generation of one million pounds of steam per hour by controlling the quantity of fuel fed to the furnaces and by regulating the air supply to suit this. Such control is a very simple matter, and is indicated on recording instruments which are adjusted to show the correct proportions of air and fuel. The stoker, therefore, becomes, to all intents and purposes, a switchboard operator.

Quite apart from the economies effected by marked reduction in space and cost of buildings there still remains one feature which should be emphasised; this is, that with this form of combustion apparatus, it is possible to generate steam from the lowest grades of fuel of any description obtainable. When it is remembered that in this country we are producing millions of tons of so-called waste coal for which, formerly, no market existed, it will be appreciated that by the use of powdered fuel a great national service is being performed. With the use of any other form of combustion apparatus specially selected coals have to be obtained. This coal often possesses characteristics which indicate that with successful carbonising treatment it would have a much larger value, and, therefore, with low-temperature carbonisation now apparently becoming a commercial prospect, it is in the national interest that all such coals should be conserved, and only those of a low-grade character should be used for the purpose of steam generation.

Emphasis has been laid on the point that this system is essentially adapted to the use of low-grade coals, but a diverse view to this is reflected in the figures quoted by the Poplar Electricity Committee in regard to the price now being paid for coal. Mr. Frank Hodges recently selected this point for comment, remarking that, in spite of the great increase in price due to the disastrous labour troubles of 1926, a reduction in the price per unit of electricity generated had been effected in Poplar, due to the adoption of pulverised fuel firing. Since the year 1922-23 the price of coal has increased from 25/5 to 39/3¼ per ton for 1926-27, while the pounds of coal used per unit sold dropped from 3.542 in the former year to 3.5 in the latter, and the capital cost per kilowatt has fallen from £28 to £26 4/- in the respective periods.

Sustained thermal efficiency.

Under test conditions, with comparable heat recovery plant in the form of air-preheaters and economisers, there is not much to choose between the thermal efficiency of stoker firing and pulverised coal firing, although the balance is in favour of the latter system. Test efficiency is, however, of secondary importance in relation to the cost of generating electric current; what really interests the power station engineer is the average efficiency taken over prolonged periods under ordinary station operating conditions, and in this connection there is no doubt whatsoever that the pulverised coal-fired boiler secures the highest efficiency. The main reason for this is that with pulverised coal firing the fuel is burned in suspension in the combustion air and forms with it what is sensibly a mechanical gas. Under these conditions, the theoretical quantity of air required for complete combustion can be closely approached, and this condition can be maintained over a wide range of boiler ratings. Other factors which contribute to the higher operating efficiency of pulverised coal firing are the greater ease of control, lower radiation losses, reduced heat loss due to combustible in the ash and reduced banking losses.

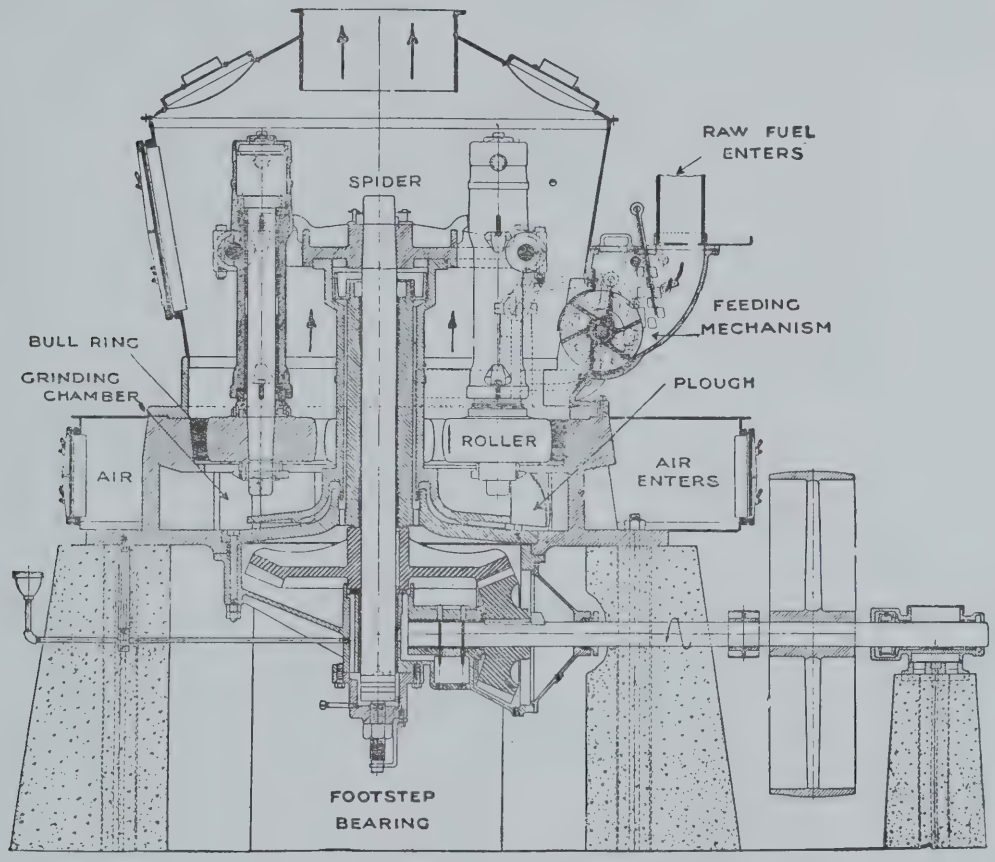
It is proved in actual practice that under the fluctuating load conditions obtaining in a power station, the average operating efficiency with pulverised fuel firing is bound to be higher than with ordinary systems, as the drop in efficiency with increase in boiler rating is considerably less with the former.

It is this fact that enables certain pulverised fuel-fired electric generating stations in the United States to be run continuously with a boiler thermal efficiency approaching 90 per cent. The following average monthly efficiencies obtained at the Lakeside Station, Cleveland, during 1925 are typical. These efficiencies are based on the gross calorific value of the fuel.

July	87.8 per cent.
August	90.1 ,,
September	90.4 ,,
October	88.4 ,,
November	90.0 ,,

Boiler size.

It is well recognised that considerable economy may be effected by the adoption of larger steam-raising and electric-generating units than are at present employed in power stations. Under the conditions obtaining, and with the load factors usual in many British power stations, increase in unit size has in the past been impracticable. Under the scheme of reorganised power production, however, the load factor in the capital stations will be considerably improved, while the large stations contemplated will enable the station load to be better distributed amongst the units installed. Much larger unit sizes are therefore



Section through Raymond Pulveriser.

practicable; in fact, boilers having capacities up to 300,000 lbs. per hour are in operation, while at the River Rouge plant of the Ford Motor Company, the boilers have been rebuilt to have a capacity of 500,000 lbs. per hour. The effect of unit size on boiler cost is shown in the following table:—

Boiler heating surface. Sq. ft.	Actual evaporation. Lbs. per hour.	Cost per lb. per hr. of boiler capacity.
30,000	327,000	4.01/-
22,000	238,000	4.29/-
12,000	130,000	4.65/-

It will also be appreciated that, apart from the direct savings effected by using boilers of large capacity, the saving in floor space and in building costs is material.

Operating costs.

A great deal of information is now available regarding operating costs with pulverised fuel, and from this it is well established that, in an average case, labour charges on a coal tonnage basis are,

approximately, 20 per cent. lower than with stoker firing, due to the greater ease of control, absence of clinker in the furnace, and lessened ash trouble, while general maintenance charges, per ton of coal fired, are 30 to 35 per cent. lower, due to the fact that in the pulverised coal boiler the maximum temperature is developed in the middle of the combustion chamber, well away from the furnace walls, while no metal parts are exposed to the action of the hot gases. Further protection to refractories is afforded by the water-cooled wall elements and the water screen. With stoker equipment, replacement of mechanical parts and repairs to refractories constitutes an important charge on the total cost of steam production. This item is all the more serious when burning coal having a high ash content. Power charges on a coal tonnage basis are admittedly about three times higher than with stoker equipment, but this increase in operating cost is invariably offset by the saving in labour and maintenance. Other factors which contribute to the general economy of pulverised fuel firing are that the system is much more flexible and more reliable, while banking losses are considerably lower.

Operating convenience.

The system has marked advantages from the operating point of view as the fuel is practically gaseous, and combustion control is as simple as with gas firing. In many installations automatic control has been introduced, and in the case of the River Rouge plant of the Ford Motor Company automatic control has been developed to such an extent that the whole operation of the plant is carried out electrically from a central control cabin. This has enabled a considerable reduction to be made in the boiler-house personnel. Apart from ease of control, no clinkering occurs in the pulverised coal-fired furnace, the ash formed being perfectly friable and easy to handle.

Metallurgical furnaces.

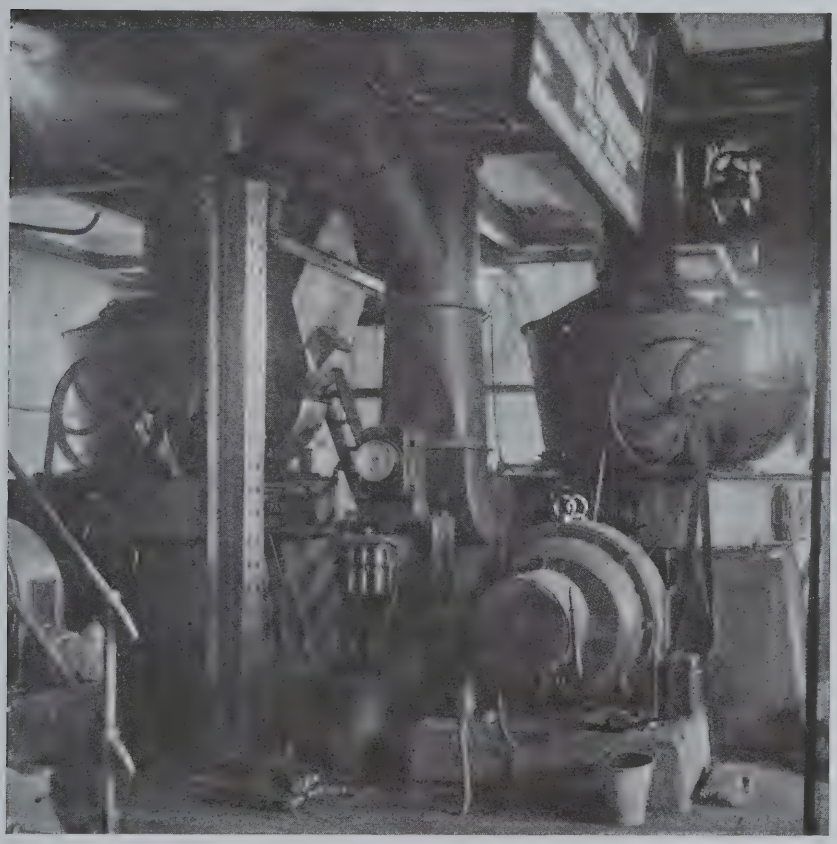
Apart from its application to steam raising, reference may be made to the use of pulverised fuel firing in the heating of industrial furnaces, as this is becoming an increasingly important development in this country, particularly in the iron and steel trades. In the United States great progress has been made in the pulverised fuel firing of metallurgical furnaces, and there it is a matter of experience that the saving in fuel with this system of firing is between 60 per cent. and 70 per cent. This application of the system is receiving a great deal of attention in the United Kingdom at the moment, and it is without doubt that before long many of our forge reheating and annealing furnaces will be converted to pulverised fuel firing.

The "Lopulco" water screen.

The use of the "Lopulco" water screen in the pulverised coal-fired boiler and the use of water-cooled walls with both pulverised fuel firing and stoker firing promises a very considerable reduction in boiler maintenance costs, as without these water-cooled elements the cost of replacing furnace refractories constitutes about one-third of the total boiler-house maintenance costs. With stoker firing a certain amount of refractory material in the form of an arch with chain-grate stokers or in the back and front wall with retort stokers will always be required to maintain combustion. With pulverised coal firing on the other hand, combustion is substantially self-supporting, due to radiation from the glowing particles of coal, and much less refractory material is required to maintain combustion than with stoker firing. From this point of view a considerable difference in the maintenance cost with the two systems of firing is likely to obtain, no matter to what extent the application of water-cooled furnace elements is likely to develop with the stoker firing. One of the latest developments with pulverised coal firing is the complete enclosure of the combustion chamber with water-cooled elements and the entire elimination of refractory brick-work. If this development finds general application the cost of furnace maintenance with the pulverised coal system will be practically negligible, except in so far that periodical tube replacement in the water-cooled elements will have to be effected in common with the rest of the boiler-heating surface. The use of water-cooled elements is not only important from the furnace maintenance point of view, but is also important in relation of the rating of the heating surface.

Eliminating the human element.

Compared with ordinary firing practice, the advantages of employing a fuel in such a form that it has to be handled by mechanical means is very obvious. Coal, as used for boiler plants, has necessarily to be of certain size, that is to say it cannot be less than a certain cubic measurement. Fuel crushed to be able to pass through a $\frac{3}{8}$-in. screen demands a method independent of manual labour to feed it into the furnace. The very nature of the fuel, therefore, practically eliminates the human element required in stoking with the ordinary boiler plant. So great is the reduction in this direction, indeed, that only one operator is needed to control a large battery of boilers. In this connection of handling the coal, other items of heavy cost and labour are involved. In any large power or industrial plant, the enormous quantity of coal which has to be dealt with is a very serious addition to the running costs of the works. Take, as an instance, the Dalmarnock Power Station where the month's supply of coal amounts to 37,500 tons or, approximately, 1,300 tons per day. It is true that the handling of this is effected automatically, but the expenditure on the necessary plant is very heavy, while the working of the various operations adds considerably to the cost of production. In addition to this, there is the great expense of ash removal and other subsidiary items which cannot increase the efficiency from the fuel consumption point of view. This expenditure would not be objected to if it secured a higher thermal efficiency, and, while it is true that a perfectly equipped plant can show a substantial saving in fuel per unit of production, the nature of the fuel prohibits a really satisfactory result. It must also be remembered that the coal burnt in such installations as those referred to is of comparatively high grade and, therefore, costly.



General View of Raymond Pulverisers at Derby Electricity Power Station.

Another and subsidiary, but none the less important, point in connection with pulverised fuel firing is that combustion is so perfect that there is no emission of smoke such as we are accustomed to endure from ordinary boiler furnaces. The smoke discharged is white in colour, carrying with it a white dust, and has no deleterious or injurious characteristics.

Wide range of coal used.

Reference has been made to the use of coal with high ash content in America, but it must not be thought that it is only economically advantageous to utilise coal of low grade or low cost. In some instances, such as the Poplar Electricity Works in this country, high-priced coal is employed with economic production. Remarkable results have been obtained with the pulverised fuel plant at Birmingham. The

coal used had a calorific value of about 8,700 B.Th.U.'s, ash content varying from 22-23 per cent., and moisture about 15 per cent., and with this material an efficiency was secured of approximately 85 per cent.

As showing the range of coal composition used in pulverised fuel plants in America, the following table is introduced:—

ANALYSES OF COAL USED AT AMERICAN PLANTS.

	Description of Coal.	Moisture p.c.	Volatile p.c.	Fixed Carbon p.c.	Ash p.c.	Sulphur p.c.	B.Th.U. per lb.	Cost per ton
Sioux City Gas & Electric...	Slack.	10.41	35.78	35.14	18.67	5.34	9,473	3.55
Union Electric L. & P. ...	—	16.73	33.81	43.15	12.31	2.20	10,872	—
Duquesne Light Co.	Penn. Bitum.	3.9	30.8	55.3	10.0	1.2	13,200	3.4
Illinois E.P. Co.	Ill.	14.0	32.0	36.0	18.0	4.0	9,700	—
Penn. Water & P. Co.	W. Va. Bitum	2.2	21.0	67.5	9.3	—	13,500	—
St. Paul Gas Light Co., Cleveland	Texas Lignite.	29.65	41.0	38.55	20.45	1.75	9,805	—
Electric Ill. Co.	Bitum.	4.5	31.5	50.6	13.4	3.2	12,100	3.90
Susquehanna Collieries Co....	Anth.	.52	7.67	72.67	19.4	—	11,952	—
United Elec. Rlys., Narragansett.	W. Va. Semi-Bit.	2.31	21.36	69.65	6.68	.93	14,100	—
Elec. Lighting Co....	W. Va. Slack.	6.5	17.0	68.5	8.0	.65	13,500	5.50
W. Penn. Power Co.	—	2.3	33.5	52.4	11.8	.95	13,100	—
Henry L. Doherty & Co. ...	Colo Lignite.	20.66	34.45	39.96	5.33	.91	9,591	1.10 at mine

A sample of pulverised coke used had the following composition:—

Moisture, per cent.	2.0	Ash, per cent.	4.12
Volatile, per cent.	11.76	Sulphur, per cent.	1.92
Fixed carbon, per cent.	82.12	B.Th.U. as received	14,569

An immediate improvement, it is stated, occurred in furnace conditions, as compared with those secured under coal.

A typical analysis of coal used in the plant of the Union Electric Light & Power Company is as follows:—

Moisture, per cent.	10.73	Sulphur, per cent.	2.20
Volatile, per cent.	33.81	Iron in ash, per cent.	22.00
Fixed carbon, per cent.	43.15	Fusing temp. of ash, deg. Fahr. ...	2,000
Ash, per cent.	12.31	B.Th.U. as received	10,872

	Cahokia.	Ashley Street.
Moisture, per cent.	10.86	10.60
Volatile matter, per cent.	33.60	33.79
Fixed carbon, per cent.	43.42	42.69
Ash, per cent.	12.12	12.92
B.Th.U.'s as received...	10,855	10,803

In the first analysis the ash fused at 2,000° F. In the latter the ash fused at 2,010° F. and contained 23.5 per cent. of iron.

Anthracite waste used at the Susquehanna Colliery plant gave the following analysis:—

Moisture, per cent.	0.52	Ash, per cent.	19.14
Volatile, per cent.	7.67	B.Th.U.'s per lb....	11,952
Fixed carbon, per cent.	72.67		

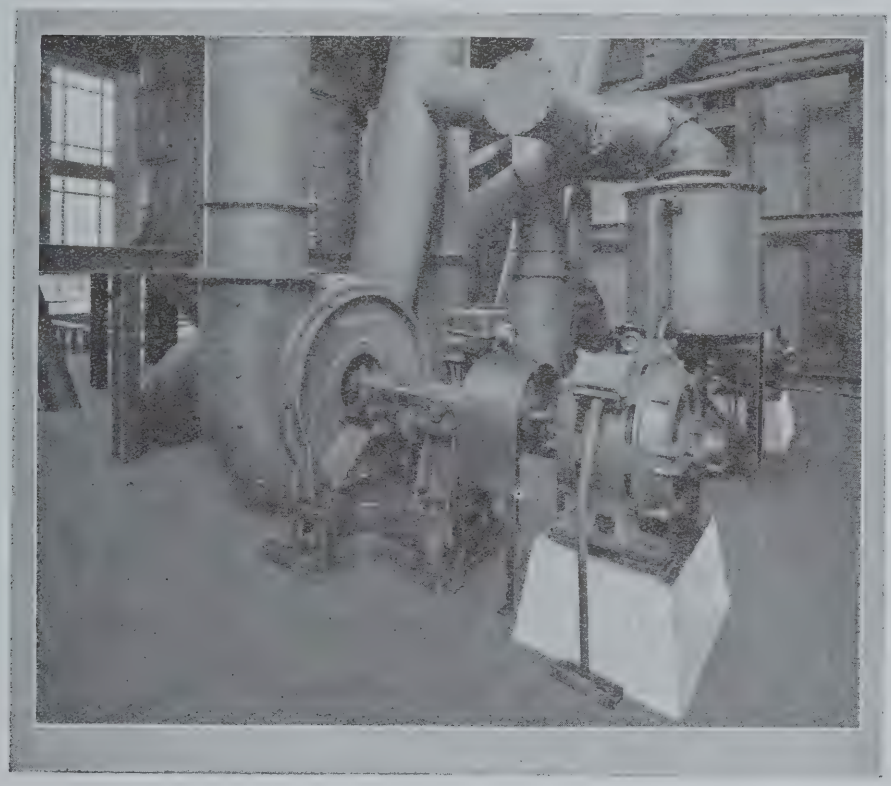
Another instance of an American plant in which Texas lignite was the fuel was of the following composition:—

Moisture (wet basis)	26.24	Fixed carbon (dry basis)	35.1
Moisture (per cent., dry coal)	35.57	Sulphur (dry basis)	2.08
Ash (dry basis)	22.54	B.Th.U.'s per lb. (dry basis)	9,564
Volatile (dry basis)	42.36		

The coal which is to be used in the Congella Power plant gives the following analysis:—

Carbon, per cent.	55-71	Moisture	1.4-2.85
Ash, per cent.	10-23	Volatile matter	14-25

The historic occasion during the coal dispute of 1926, when the Birmingham Electricity Works were compelled to resort to pit mound material also emphasises the wonderful adaptability of pulverised fuel firing. This material had a calorific value of only about 4,500 B.Th.U.'s and an ash content of about 35 per cent.



General View of Dryers at Derby Electricity Power Station.

The handling of moist coal.

One of the difficulties which has to be faced in certain districts is the handling of moist coal in the conveying plant which transports the fuel from the stockyard to the boiler house. This difficulty arises principally during wet weather, even when using pearls and with washed duff and dry slack in pulverised form, although the moisture content at the pit is comparatively low, it will certainly increase in transport and while in storage if the coal is exposed to rain or snow, and the difficulty of fuel transport would be accentuated. There are several methods of overcoming this difficulty: (*a*) By installing coal-drying equipment in the stockyard; (*b*) by locating the whole of the pulverising equipment over the stockyard and pumping the pulverised coal to the bins over the boilers; (*c*) by reconstructing the coal-conveying equipment to enable it to handle moist low-grade fuel. Any one of these alternatives is quite practicable. The additional capital cost of alternatives (*a*) and (*c*) would be quite moderate, while the additional cost of alternative (*b*) might not prove to be prohibitive. Possibly the most satisfactory solution in such cases would be to lay down additional drying equipment at the stockyard, as this would considerably widen the choice of fuels as regards moisture content, and would enable the concern to buy fuels at a lower cost per unit of heat than those recommended above, i.e., air-dried slurry, etc.

BRITISH "LOPULCO" PLANTS OPERATING.

The first operating year of pulverised fuel firing in this country on any large scale was 1925, that is, only two years ago. The economy and high efficiency of using coal in this form had long been proved in America, and

once British power engineers had witnessed for themselves the advantages of the system, doubts and prejudices were removed and they recognised in it the means of securing fuel economy and that this was combined with the facility of securing higher efficiencies from their plants. Not only this, however, but it was recognised that this form of firing provided greater flexibility than other methods.

The conditions governing fuel supplies in America admittedly differ from those in this country, but from an economic point of view the necessity of extracting from coal every heat unit possible is more urgent. By pulverising the coal and spraying it into the furnace, it is clear that more perfect combustion can be attained than by any other method, while it provides the greatest facility for burning every description of solid fuel with the highest efficiencies. British power station engineers, who have visited American plants and have studied the applicability of pulverised firing to British conditions, have unhesitatingly advocated and adopted this system for their generating stations.

Birmingham.

Birmingham was one of the first to adopt this form of firing and equipped the Prince's Power Station at Nechells with Lopulco equipment comprising four 6-ton pulverising units, with dryers, being installed for supplying powdered fuel to six Vickers-Spearing boilers. Each of these has a heating surface of 5,400 sq. ft. arranged for a working pressure of 320 lbs. per sq. inch, and provided with superheaters for raising the temperature of the steam to 700° F. The normal evaporation of each boiler is 35,000 lbs. per hour, and the maximum 42,000 lbs. per hour.

The chief electrical engineer of the Birmingham Corporation Electricity Works has stated that the operation of the boiler is very flexible, and the output can be easily adjusted. It is his experience also that very much more perfect combustion of the fuel is obtained, there being practically no carbon left in the ash residue.

In view of the experience gained by the city electrical engineer for Birmingham, he recommended the Electricity Committee to instal five large units at the new super power station at Hams Hall. Each of the boilers will have a capacity of 200,000 lbs. of steam per hour with a maximum rating of 240,000 lbs. per hour, so that two of the boilers can easily supply steam for running one of the 30,000 kw. turbo-generators with full load. These boilers will be equipped with air heaters in place of economisers, and superheaters will be included which will raise the temperature of the steam to 750° F. In order to secure the greatest economy, steam will be bled from three stages of the main turbine, so that the feed water may be heated to a temperature of 295° F. In this way it is hoped to obtain a thermal efficiency at this capital station of 23.5 per cent.

The first section at the Hams Hall Capital Station will be of 60,000 kw. capacity, the complete station being of a capacity of 210,000 kw. There is, however, sufficient room for four stations on the site, so that the total capacity can be 840,000 kw. The station will be laid out to feed the whole of Birmingham, and will be linked up with the Princes Power Station as well as with Summer Lane and the Stourport Station of the Shropshire, Worcestershire and Staffordshire Electric Power Company. International Combustion Limited are the main contractors for this scheme.

Other important installations operating or in course of construction in the United Kingdom are set out, in brief, below:—

Derby Borough Council Electricity Dept.

The plant here consists of two B. & W. boilers, each 60,000 lbs. N.R. with maximum of 80,000 lbs., and operated with the " Lopulco " system of pulverised fuel firing. The working pressure is 300 lbs. per sq. inch. This plant, housed in one of the finest power station buildings in the country, has already attracted the attention of many important engineers from all parts of the world.

Over a period of 14 months' operation an efficiency of 84.6 per cent. has been established, whilst maintenance costs on the boilers and pulverising plant, including the cost of the annual survey, have been officially returned at 8d. per ton. 25,000 tons of coal have been pulverised, one mill having ground 12,000 tons prior to any repair being necessary, the other mill grinding 13,000 tons of coal before any changes were requisite.

Analysis and Grading of Coal used at Derby Electricity Works. The raw coal now being consumed on our " Lopulco " plant is regularly graded and the figures supplied by the West Ham testing laboratory denote that our raw coal all passes a $\frac{3}{16}$in. mesh.

An analysis of a sample of pulverised fuel taken during a recent test was as follows:—

Total moisture	8.18 per cent.
Volatile	26.33 ,,
Fixed carbon	43.65 ,,
Ash	22.07 ,,
Calorific value	10,009 B.Th.U.

Result of an Eight-hours' Test.

Coal consumed	59,750 lbs.
Water evaporated	446,500 lbs.
Feed water inlet	121.17 degrees F.
Feed water outlet	298.47 degrees F.
Average CO_2	13.5 per cent.
Average final exit gas temperature	308 degrees F.
Average final steam temperature	296 lbs. gauge.
Efficiency ... $\frac{7.5 \times 1,375.7 - 89.17}{10.009}$ =	88.45 per cent.

Twenty-four Hours' Boiler Test, September 5th and 6th.

Duration of test	24 hours.
Total water evaporated	1,262,000 lbs.
Total coal burnt	189,600 lbs.
Average flue gas temperature outlet	290.6 degrees Fahr.
Pounds of water evaporated per lb. of fuel	6.656
Average steam pressure	315 lbs. per sq. in. absolute.
Calorific value of fuel as fired	10,009 B.Th.U./lb.
Percentage efficiency of boiler	85.33 per cent.

General Data, Twenty-four hours' Test, September 5th and 6th.

Total units generated by turbine	103,850
Total coal consumed	189,600 lbs.
Coal per unit generated	1.826 lbs.
Calorific value of fuel	10,009 B.Th.U./lb.
B.Th.U. per unit generated	19.276
Thermal efficiency	18.68 per cent.

Auxiliaries.

Total units for turbine auxiliaries	2,720
Units per ton for pulverising, conveying, etc. ...	24.5
,, ,, fan equipment	21.0
Average steam consumption per unit generated ...	10.158 lbs.

Summary of Test, September 5th and 6th, 1927.

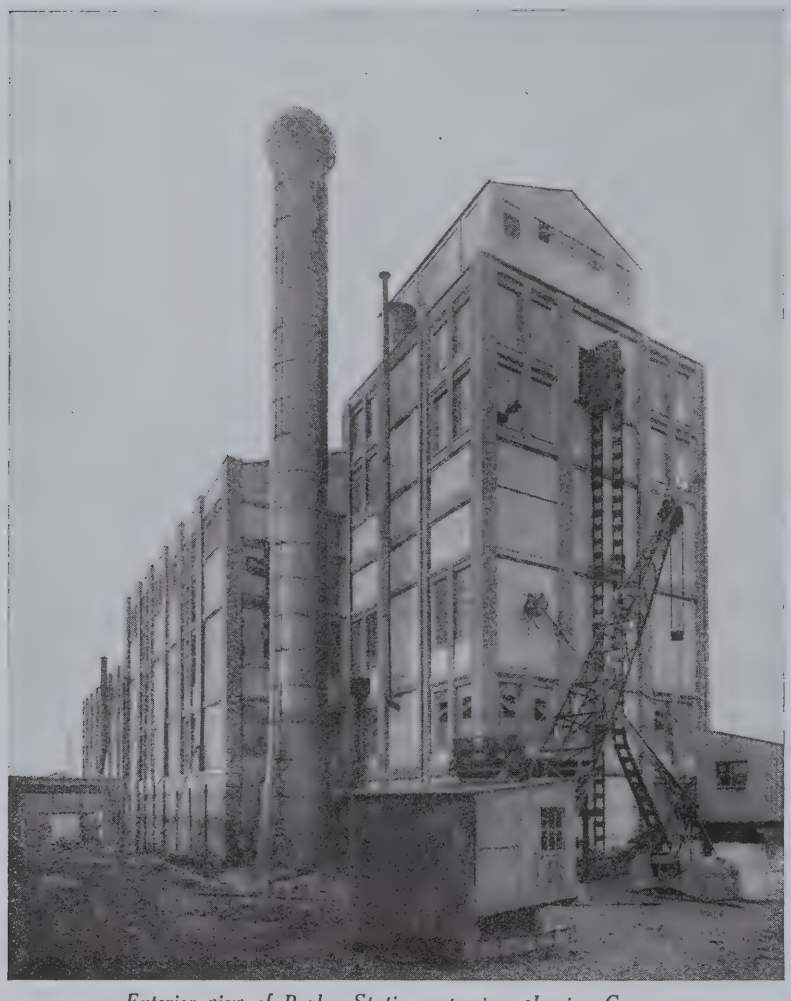
Units generated by turbine	103.850
Units for turbine auxiliaries	2,720
Units for boiler house auxiliaries	3,850
Units generated to feeders	97,280
Fuel consumed	189.600 lbs.
Fuel per unit to feeders	1.949 lbs.
Calorific value of fuel	10,009 B.Th.U./lb.
B.Th.U. per unit to feeders	19.507
Load factor	43.25 per cent.

Coal Consumed. We have during our first 14 months consumed 25,000 tons of coal. Of this amount 12,000 tons of coal were pulverised on our No. 2 mill, when it became necessary to change the six rollers, and the balance, 13,000 tons of coal, have been pulverised on the No. 1 mill without renewals during this period.

Costs per ton of Coal Consumed. Tons of coal consumed, 25,000; total costs of renewals, £836 6s. 9d.; 200,721 pence divided by 25,000=8.02d. per ton. This covers all boiler house repairs costs.

St. Pancras Borough Council Electricity Dept.

The plant here consists of two B. & W. boilers, each 60,000 lbs. N.R.; two Vickers-Spearing boilers, each 70,000 lbs. N.R. This plant is operated with the " Lopulco " system of pulverised fuel firing and is working at a pressure of 220 lbs. per sq. inch. The plant has been in operation since 1926.



Exterior view of Poplar Station extension, showing Conveyors for raw coal from barges.

Poplar Borough Council Electricity Dept.

This plant consists of three Vickers boilers each of 50,000 lbs. normal evaporation and overload of 70,000 lbs., and is equipped with the " Lopulco " system of pulverised fuel firing. The working pressure is 325 lbs. per sq. inch, and the final temperature of the steam is 700-714° F.

Stockton - on - Tees (Synthetic Ammonia & Nitrates Co., Ltd.).

Two John Thompson boilers, normal evaporation each 50,000 lbs. and maximum evap. 87,000 lbs. N.R. Each boiler is arranged to have a working pressure of 275 lbs. per sq. inch. The extension to this plant, also fired by pulverised fuel on the " Lopulco " system, consists of four John Thompson horizontal tube-type boilers each 15,000 sq. ft. heating surface with a normal rating of 120,000 lbs. and a maximum rating of 135,000 lbs. per hour. These are the largest boilers at present in operation in this country.

Shell Haven (Shell-Mex, Ltd.).

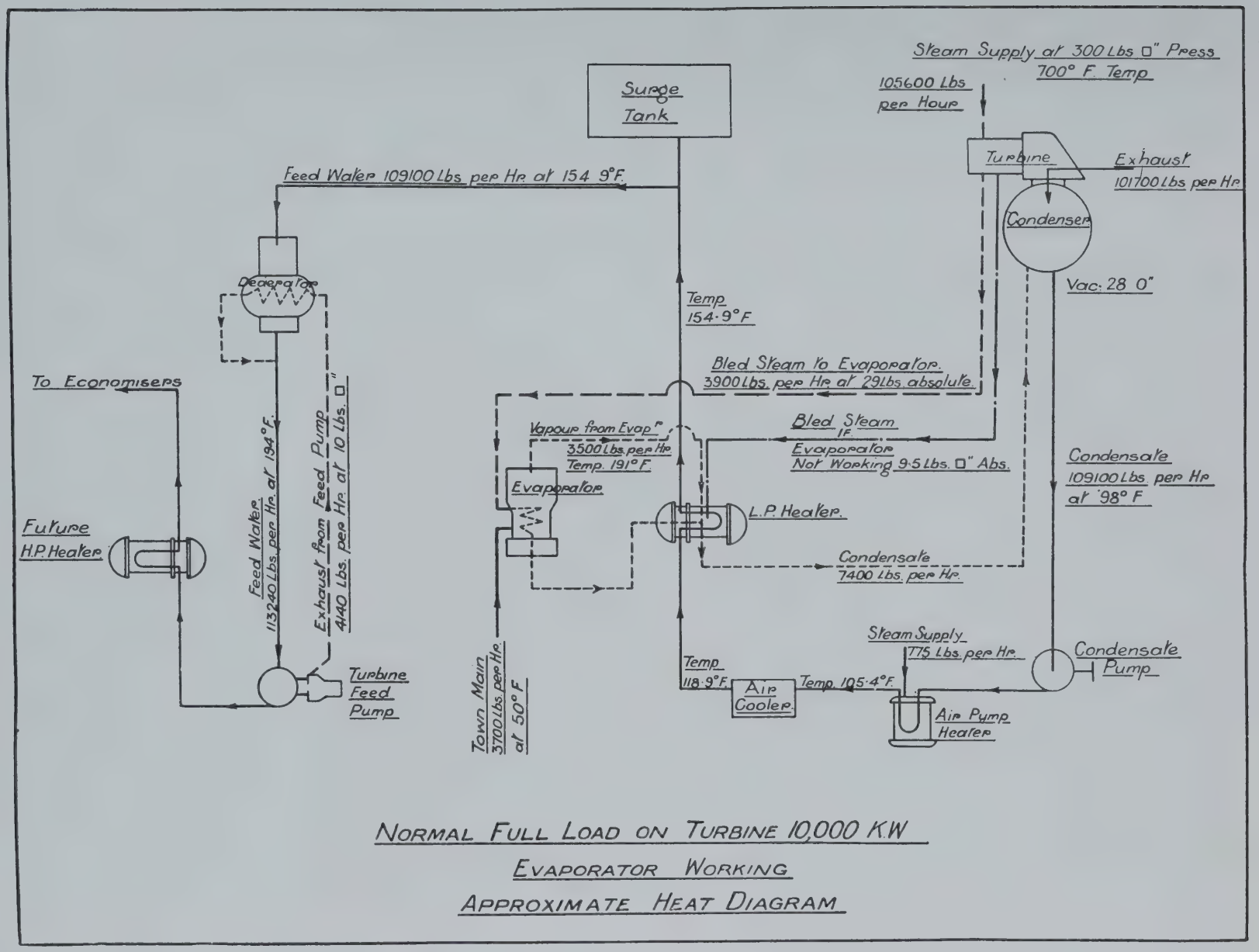
The plant here consists of three B. & W. boilers with normal evap. of 42,000 lbs. each and maximum evap. of 60,000 lbs. The working pressure is 160 lbs. per sq. inch, and is operated with the " Lopulco " system.

Ashington Colliery Co., Ltd., Durham.

The plant here consists of four Stirling boilers; normal evap., 40,000 lbs. normal rating each. The working pressure is 200 lbs. per sq. inch. The combustion chambers are equipped with Murray fin furnace walls, and the plant is one of the most up-to-date of any colliery in the United Kingdom.

County of London Electricity Dept., Barking.

The plant here consists of ten B. & W. boilers each normal evap. of 135,000 lbs. and overload capacity of 187,500 lbs. Steam will be generated at a working pressure of 375 lbs. per sq. inch. The " Lopulco " central system of pulverised coal firing is to be adopted, the main features of which are briefly described here. Above and in front of each line of boilers are two lines of raw coal bunkers having a capacity of about 2,500 tons of coal, the raw coal being fed to these by an elevator. A magnetic separator,


Steam Supply at 300 Lbs □" Press
700° F. Temp
105600 Lbs per Hour
Surge Tank
Turbine
Exhaust
101700 Lbs per Hr.
Condenser
Vac: 28 0"
Feed Water 109100 Lbs. per Hr. at 154 9°F.
Deaerator
Temp 154·9°F
To Economisers
Bled Steam to Evaporator. 3900 Lbs. per Hr. at 29 Lbs. absolute
Vapour from Evap"
3500 Lbs. per Hr.
Temp. 191° F.
Bled Steam
1F.
Evaporator Not Working 9·5 Lbs. □" Abs.
Condensate 109100 Lbs. per Hr. at 98° F
Evaporator
L.P. Heater.
Future H.P. Heater
Feed Water 113240 Lbs. per Hr. at 194°F.
Exhaust from Feed Pump 4140 Lbs. per Hr. at 10 Lbs. □"
Condensate 7400 Lbs. per Hr.
Steam Supply 775 Lbs. per Hr.
Condensate Pump
Temp 118·9°F.
Air Cooler
Temp. 105·4°F.
Air Pump Heater
Turbine Feed Pump
Town Main 3700 Lbs. per Hr. at 50° F

NORMAL FULL LOAD ON TURBINE 10,000 K.W.

EVAPORATOR WORKING

APPROXIMATE HEAT DIAGRAM

General view of "Lopulco" Dryers and Exhausters at Poplar.

General view of Feeder Gallery at Poplar.

removing tramp iron or other foreign matter from the coal, is located between the receiving hopper and the raw coal elevator fillers. From the bunkers the raw coal is discharged through coal gates to the dryers, which are of the steam-heated rotary type, driven by a 3-H.P. variable speed motor. There will be two dryers per boiler unit. When the coal contains not more than six per cent. free moisture the raw coal will be fed by means of a by-pass chute direct from the raw coal bunker to the pulverising mills.

General view of "Lopulco" Burners and Recording Instruments at Poplar.

The mills, one per boiler unit, are to be of the Raymond roller type, each having a capacity of 15 tons per hour.

NORTH METROPOLITAN ELECTRIC POWER SUPPLY CO.—BRIMSDOWN SUPER-POWER STATION.

The plant at the North Metropolitan Electric Power Supply Co. consists of five B. & W. CTM-type boilers, each with normal evaporation of 101,000 lbs. and maximum 125,000 lbs., and is laid out on similar lines.

Among the foreign contracts secured by International Combustion, Ltd., are:—

CONGELLA, DURBAN.

The plant consists of four B. & W. CTM-type boilers, each with normal evap. of 60,000 lbs. The working pressure is 270 lbs. per sq. inch. The main contract for this important new station has been awarded to International Combustion Limited, and the whole of the steam generating plant will be operated with the "Lopulco" system and will be complete with automatic control.

SHANGHAI MUNICIPAL COUNCIL.

This plant consists of three boilers fitted with "Lopulco" system of feeding and burning with normal evap. of 185,000 lbs. and at a working pressure of 375 lbs.

Buenos Ayres Electricity Dept.

The plant being installed consists of the complete " Lopulco " equipment, including combustion chambers with Murray fin furnace walls for eight B. & W. boilers each having normal evaporation of 145,000 lbs. and a maximum evaporation of 226,000 lbs., with a working pressure of 600 lbs. per sq. inch.

Perak (Malay Peninsula).

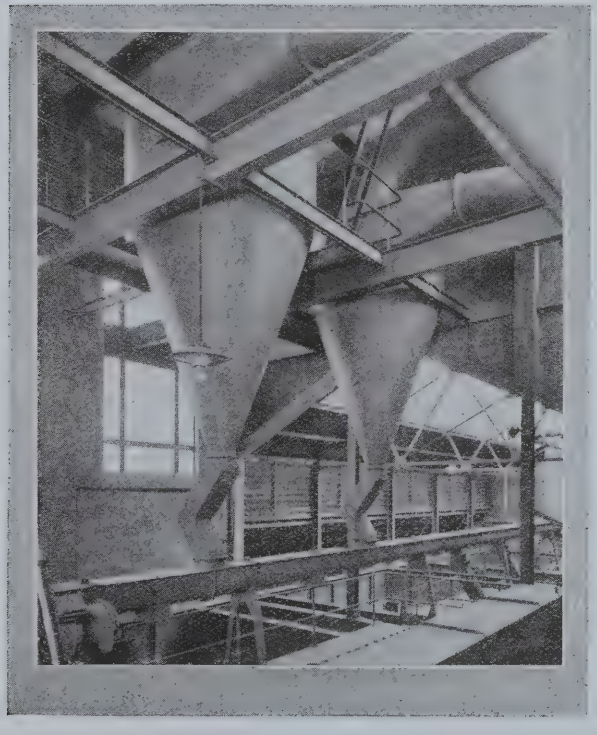
The complete power station for the Perak Hydro-Electric Power Co. to be operated with pulverised fuel.

Germany's endorsement.

It is a well-known fact that Germany is adopting every means to produce electricity at a minimum cost, and the principal factor in achieving this is the adoption of pulverised fuel for firing the boilers of the large plants which have been installed.

The problem which the Germans had to envisage was whether they should erect these stations on the brown coalfields, where large quantities of water were not available for condensing purposes, and where, therefore, the same efficiency in the steam plant could not be realised, or whether it would be better for them to erect their work where plenty of water was available, and to carry the coal from the coalfields to the works. The calculations resulted in the adoption of the principle that these great generating works should be arranged directly on the brown coalfields. After being handled by the dredger the coal was tipped directly into trucks, weighed, and taken by means of a chain in most cases and put either into the bunkers for the boilers or into the coal stock. They were producing current at a very low rate and transmitting it over very considerable distances.

The power stations on the River Spree consist of three 80,000 kw. turbo-alternator sets with 16 boilers providing a heating surface of 16,000 sq. ft. each. These boilers are fired with pulverised coal on the " Lopulco " system.

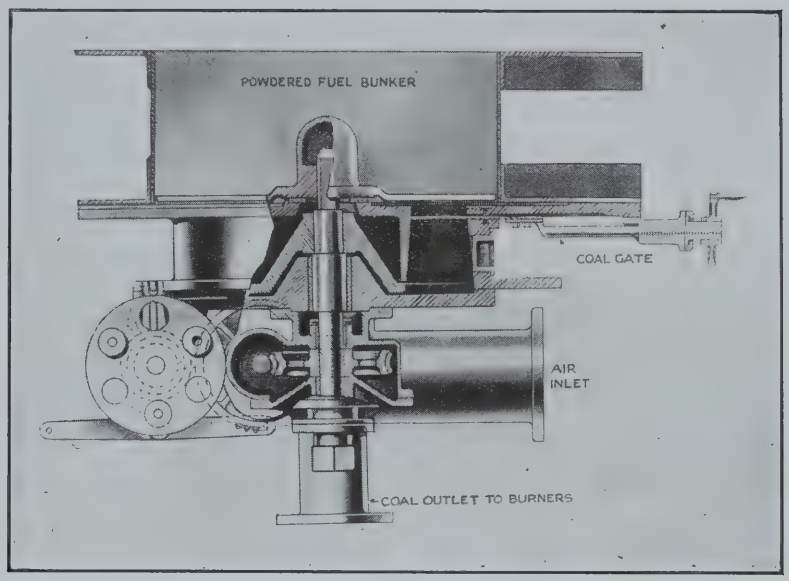


Cyclone Collectors and Screw Conveyor at Derby Electricity Works.

Another station which may be referred to is the new super-power station at Bohlen, the generating equipment of which consists of five 25,000 kw. units. This station has recently been completed, and is one of the four stations needed to supply the power requirements of the State of Saxony. The station is located in a district having a virtually unlimited supply of brown coal which is mined by means of open-working. The deposits in this district occur at a depth of about 150 feet, the fuel containing between 55 and 60 per cent. of moisture. A very efficient means of drying was in operation at the mine, reducing the moisture down to 15 per cent. In this state it is taken to the pulverisers and thence fed by pneumatic transport to the boiler house 700 yards away, and burnt under the largest boilers in Europe. Of these, eight are installed having a heating surface of 22,000 sq. ft. each. They are equipped with 21 " Lopulco " burners, the furnaces being fitted with " Murray fin walls." This is the first electric power installation in Europe successfully employing this low-grade coal with high moisture content in pulverised form.

United States.

The great success of pulverised fuel firing is indicated by the fact that there are over 200 plants in operation or under construction in the United States and Canada, and that these include power stations, metallurgical works, and a variety of industrial works. Not only this, but a considerable number of extensions have been made to the original unit installed showing that great economies and higher efficiencies have been attained than under the old system of firing. It is of interest to note also that of the 70 plants adopting the bin and feeder system, no less than 43 were equipped with "Lopulco" feeders and burners and Raymond type mills.



"Lopulco" Duplex Feeder.

American practice.

The following is a record of the boiler efficiencies obtained. The monthly figures are averages of the overall efficiency for the month, including banking losses. The boiler ratings given are for the steaming period only. The ratio of economiser to steam-making surface is 0.65.

Month.	Average efficiency. Entire period. Boiler and Economiser.	Boiler.	Per cent. Average boiler rating, Steaming period.
January	85.1	—	192.7
February	85.9	—	185.4
March	83.7	76	193.2
April	85.6	78	202.0
May	86.6	78	206.2
June	85.5	78	215.5
July	89.1	80.6	217.5
August	86.4	77.4	222.0
September	89.1	80.4	225.7
October	86.0	77.7	224.3
November	85.1	76.7	225.2
December	86.6	78.3	215.6
Average	86.2	77.8	211.5

General view of Boiler House of Pulverised Fuel Installation at Ford's Motor Works, Detroit, U.S.A.

Figures obtained by the Pennsylvania Water & Power Company when using varying proportions of anthracite also indicate the high efficiencies obtained on a low volatile coal.

Month.	Anthracite burned, per cent. of total.	Average boiler rating, steaming period. per cent.	Boiler efficiency, per cent.
January	8.0	201	81.4
February	30.3	190	73.2
March	73.1	195	74.9
April	37.7	194	73.0
May	36.5	214	75.1
June	16.2	197	79.3
July	31.7	219	79.1
August	9.6	184	81.4
September	0.7	188	79.4
October	92.8	214	76.6
November	96.7	217	81.0
December	39.7	201	76.5
Average	36.6	201	79.6

Slightly more than one-third of the 46,852 tons of coal burned was anthracite coal that had been dredged from the bottom of the Susquehanna River. The average heating value of all the coal burned during the year was 12,350 B.Th.U. per lb. The average moisture and ash contents of the coals burned were:—

	Anthracite.	Bituminous.
Moisture, per cent.	13.0	3.8
Ash, dry basis, per cent.	16.7	11.1

A large part of the bituminous coal burned was of an inferior quality, whose ash content was as high as 20 per cent. The fusing temperature of most of the ash formed during the year was moderately low, varying from 2,150 to 2,550 deg. Fahr.

The efficiencies obtained by the Public Service Co., Colorado, burning lignite as fuel with moisture content varying from 19.25-28.58 per cent., and ash from 3.68-6.73 per cent., were boiler and superheater 79.71-80.57 per cent., and on boiler, superheater and integral economiser 82.03-85.74 per cent. The calorific value of the fuel as fired carried between 9,967 and 10,110 B.Th.U.'s per lb.

A recent issue of the report of the Prime Movers' Committee of the National Electric Light Association of New York records in a comprehensive manner the series of a number of large power stations in which pulverised fuel is employed. From these the results obtained at the Milwaukee Electric Railway and Light Co. are selected as one of value to power engineers in this country. The steam-raising plant consists of eight boilers of 13,060 sq. ft. heating surface each, eight of 17,500 sq. ft., and one of 28,830 sq. ft. heating surface. The first set of boilers is equipped with six "Lopulco" burners each, the second set with ten burners each, and the large boiler with twelve "Lopulco" burners.

Three months' operation of the 1,300-lb. pressure boiler unit, having a totally water and steam-cooled furnace, has shown that no combustion difficulties have resulted because of the large amount of cooling surface present in this furnace.

During operation, 16½ per cent. CO_2, corresponding to 13 per cent. excess air, is regularly maintained. The unit was operated at 16 per cent. CO_2 for two months, and more recently 16½ per cent. CO_2 has been averaged. Readings as high as 17½ per cent. CO_2, corresponding to 8 per cent. excess air, have been maintained over short periods without any CO. Combustible in the flue gas is not in excess of ⅓ per cent., as shown by samples taken from the air heater outlet duct.

Other details can be obtained on application from :—

INTERNATIONAL COMBUSTION LIMITED,

AFRICA HOUSE, KINGSWAY, W.C.2.

TELEPHONE : HOLBORN 2002-5. TELEGRAMS : LOPULCO WESTCENT LONDON.

List of chief "Lopulco" Pulverised Fuel Plants Installed Throughout the World.

GREAT BRITAIN and IRELAND.

Name of Installation.	No. of Boilers.	Name of Boiler.	Heating surface per Boiler sq. ft.
Birmingham Corp. Elec. Supply.	6	Spearing	5,400
Derby Corp. Electricity Supply.	2	B. & W.	8,850
Met. Borough St. Pancras London (1st order).	2	B. & W.	6,546
Met. Borough St. Pancras, London (2nd order).	2	Spearing	6,070
Met. Boro. Poplar, London.	3	Spearing	6,200
York St. Flax Spinning Co., Belfast, Ireland.	1	B. & W.	9,270
Synthetic Ammonia and Nitrates, Ltd. (1st order), Stockton-on-Tees.	2	Thompson	9,000
Synthetic Ammonia and Nitrates, Ltd. (2nd order)	4	Thompson	14,500
North Met. Elec. Power Supply Co., Brimsdown (1st order).	2	B. & W.	1,966
North Met. Elec. Power Supply Co., Brimsdown (2nd order).	5	B. & W.	10,032

GREAT BRITAIN and IRELAND—Continued.

Name of Installation.	No. of Boilers.	Name of Boiler.	Heating surface per Boiler sq. ft.
North Met. Elec. Power Supply Co., Willesden, London.	1	B. & W.	7,200
Ashington Coal Co., Durham	4	Stirling	5,904
Pilkington Bros., St. Helens.	1	B. & W.	8,280
Stewart & Lloyds, Ltd., Coatbridge.	1	B. & W.	2,700
Shell Mex, Ltd., Shell Haven, Essex.	3	B. & W.	7,320
County of London Elec. Supply (Barking)	10	B. & W.	16,510
Metro Carriage Wagon and Finance Co., Ltd., Birmingham.	1	Vickers	4,800
West Mid. Joint Elec. Authority.	3	Thompson	8,560
Hams Hall, Birmingham (Complete 60,000 kw. station).	5	Thompson	20,000
Anglo-Persian Oil Co. (Oil fired).	2	Thompson	8,000

FRANCE.

Name of Installation.	No. of Boilers.	Name of Boiler.	Heating surface per Boiler sq. ft.
Union d'Electricite, Gennevilliers.	4	Ladd-Belleville ..	19,700
	1	Mercier	
Union d'Electricite, Vitry.	4	Ladd-Belleville ..	17,800
Mines de Lens	2	Stirling	7,300
Societe d'Electricite de Strasburg.	2	Stirling	10,760
Mines de Sarre et Moselle..	2	Garbe S.A.C.M.	10,760
Soc. Mines d'Electricite La Houve.	1	B. & W.	9,950
Establissements Lanhoffer La Grande Paroisse.	2	2 S.A.C.M. ..	268
Compagnie Parisienne de Distribution d'Electricite, Issy-les-Moulineaux.	3	2 Fives-Lille ..	
		1 Fives-Lille ..	19,400

BELGIUM.

Soc Intercom Belge Alost ..	2	B. & W.	6,500
Soc Intercom Belge Swevegham.	2	Niclausse	5,620
Soc Intercom Belge Bressoux	2	Ladd-Belleville ..	8,860
Soc Metallurgique de Hoboken.	2	Kestner	3,230
Raffinerie Electrolytique Hoboken.	3	Ladd-Belleville ..	5,320
Charbonnages de Beeringen.	4	Ladd-Belleville ..	6,420
Societe d'Electricite de la Campine.	5	Ladd-Belleville ..	4,850

HOLLAND.

Staatsmijene Heerlen Zeche Mauritz.	4	B. & W.	11,300

ITALY.

Soc. Ligure Toscana di Electricite Cent di Livorno.	2	Tosi	12,870
	2	B. & W.	12,870
Azieda Elettrica Municipale, Milano.	2	Ansaldo-Buttner	9,130

GERMANY.

I.G. Farbenindustrie, Ludwigshafen.	1	Double Vertical Tube K.S.G. Hanomag	18,800
Zeche M. Stinnes, 3/4, Essen	1	Double Flue ..	1,776
Zeche M. Stinnes, 1/2 Essen (2nd order).	1	Garbe	7,100
A.G. Sachs Werke, Hirschfelde.	1	Garbe	6,800
Gelsenkirchener Bergwerks A.G. Zeche, Furst Hardenberg.	2	Vertical Tube Petry Dereux	3,700
Zeche Lothringen bei Cochum.	1	Vertical Tube Hanomag	6,450
Berliner Elektr. Werke Moabit.	2	Inclined Tube Borsig	6,320
Berliner Elektr. Werke Gro. Rummelsburg (2nd order).	12	8 Vertical Tube	17,200
		1 Hanamag	
		1 Piedboeuf	
		1 Steinmuller	
		1 Linke Hofmann-Lauchhammer	
		3 Borsig	
		1 Durr	
		4 Inclined Tube	
		3 Borsig	
		1 German B. & W.	

GERMANY—Continued.

Name of Installation.	No. of Boilers.	Name of Boiler.	Heating surface per Boiler sq. ft.
A.G. Sachs Werke, Bolen ..	2	Inclined Tube German B. & W.	21,500
	6	Vertical Tube	16,080
		2 Oschatz	
		2 Humboldt	
		1 Hanamag	
		1 Hartmann	
	1	Vertical Tube Borsig	10,760
Stadt Elektr. Werke, Dresden	1	Inclined Tube Borsig	10,760
Stadt Elektr. Werke, Hamburg.	1	Vertical Tube Borsig	8,600
Stadt Elektr. Werke, Stuttgart.	1	Inclined Tube German B. & W.	9,680
Gelsenkirchener Bergwerks A.G. Schact Grillo.	3	Vertical Tube Petry Dereux	4,300
Zeche Heinrich Uberruhr ..	1	Vertical Tube K.S.G. Buttner	5,660

AUSTRALIA.

Broken Hill Proprietary, Newcastle, N.S.W.	3	B. & W.	9,273

AFRICA.

Elec. Supply Commission, Durban, South Africa.	4	B. & W.	7,150
Societe Miniere du Haut Katanga.	4	Ladd-Belleville ..	7,100

CHINA.

Shanghai Municipal Elec. Dept.	2	B. & W.	14,500
	1	Stirling	15,000

JAPAN.

Nippon Elec. Co., Kobe ..	4	B. & W.	13,850
Kobe Municipality, Kobe ..	1	B. & W.	5,500
Toho Elec. Co., Hakata, Kiushu.	1	B. & W.	8,000
Nippon Elec. Power Co., Amagasaki.	4	B. & W.	11,100

MALAY STATES.

Perak Hydro-Electric Power Company.	3	Thompson	5,380

S. AMERICA.

Compania-Hispano Americana de Electricidad (Spain) for Buenos Ayres.	6	B. & W.	15,400
	2	B. & W.	4,780
El Charquito, Bogota, Colombia.	2	Springfield ..	3,475
El Charquito, Bogota, Colombia.	2	Springfield ..	3,480

UNITED STATES and CANADA.

Milwaukee E.R. & L. Co., Oneida Street Station, Milwaukee, Wisc.	5	Edge Moor ..	5,040
Morris & Co., Oklahoma City, Okla.	5	Edge Moor ..	5,380
	2	Edge Moor ..	3,225
Lima Locomotive Co., Lima, Ohio.	6	Wickes	4,310
	1	Heine	5,380
St. Joseph Lead Co., Rivermines, Mo.	2	Stirling	8,260
Milwaukee E.R. & L. Co., Lakeside Station, Milwaukee, Wisc.	6	Edge Moor ..	14,000
Allegheny Steel Co., Brackenridge, Pa.	7	Wickes	3,580
	1	Erie City	4,310
Ford Motor Co., River Rouge, Michigan.	4	Ladd-Belleville ..	28,480

UNITED STATES and CANADA—Continued.

Name of Installation.	No. of Boilers.	Name of Boiler.	Heating surface per Boiler sq. ft.
Milwaukee E.R. & L. Co., Lakeside Station, Milwaukee, Wisc.	2	Edge Moor ..	14,000
Duquesne Light Co., Brunot's Island Plant.	1	Stirling	8,850
West Penn Power Co., Springdale, Pa.	1	B. & W.	16,500
Penn. Salt Mfg. Co., Wyandotte, Mich.	1	B. & W.	8,850
Union Elec. Light and Power Co., Cahokia, East St. Louis, Ill.	8	B. & W.	19,400
St. Joseph Lead Co., Rivermines, Mo.	2	Stirling	8,260
United Electric Railways Co., Providence, R.I.	3	Bigelow-Hornsby	13,580
Rochester Gas & Elec. Corp., Rochester, N.Y.	2	Bigelow-Hornsby	9,400
Ford Motor Co., River Rouge, Mich.	4	Ladd	28,480
Firestone Tire & Rubber Co., Akron, Ohio.	3	Stirling	6,450
Ford Motor Co. of Canada, Ltd., Ont.	3	McAleenan ..	14,550
St. Joseph Lead Co., Rivermines, Mo.	1	Heine	16,180
Cleveland Elec. Light Co., Lakeshore Station, Ohio.	4	Stirling	33,000
Milwaukee E.R. & L. Co., Lakeside Station, Wisc.	8	Edge Moor ..	18,800
Farr Alpaca Co., Holyoke, Mass.	3	Wickes	11,250
St. Paul Gas Light Co., Island Station, Minn.	3	Heine	11,230
Duquesne Light Co., Colfax Station, Pa.	5	B. & W.	29,500
Metropolitan Power Co., Middletown, Pa.	3	Connelly	15,800
Public Service Co. of Colo. Valmont, Colo.	4	Bigelow-Hornsby	15,500
Detroit Edison Co., Detroit, Mich.	6	Stirling	31,250
Allegheny City, Steam Heat, Pittsburgh, Pa.	1	B. & W.	32,200
Mid-continent Petrol Corp., West Tulsa, Okla.	8	Heine	5,380
Ohio Brass Co., Mansfield, Ohio.	2	Stirling	3,760
Farr Alpaca Co., Holyoke, Mass.	1	Wickes	11,250
Pejepscot Paper Co., Lisbon Falls, Mo.	2	Stirling	4,040
Illinois Elec. Power Co., Peoria, Illinois.	4	Springfield ..	15,500
Ford Motor Co., Iron Mountain, Michigan.	2	McAleenan ..	14,630
City of Winnipeg, Manitoba, Canada.	3	Erie City	11,810
Virginian Railway Co., Narrows, Virginia.	5	Springfield ..	16,400
Ford Motor Co., Twin Cities Plant, Minn.	2	McAleenan ..	14,630
Ohio River Edison Co., Toronto, Ohio.	4	B. & W.	2,410
St. Joseph Lead Co., Rivermines, Mo.	2	Heine	10,760
Pennsylvania Cement Co., Bath, Pennsylvania.	1	Edge Moor ..	5,420
Union Electric Light and Power, Cahokia Station, E. St. Louis.	4	B. & W.	19,400

UNITED STATES and CANADA—Continued.

Name of Installation.	No. of Boilers.	Name of Boiler.	Heating surface per Boiler sq. ft.
Ford Motor Co., Iron Mountain Plant, Mich.	2	McAleenan ..	14,650
Sioux City Gas & Elec. Co., Sioux City, Iowa.	3	Stirling	11,950
Cleveland Elec. Ill. Co., Cleveland, O.	3	Stirling	16,150
Allegheny County Steam Heating Co., Pittsburgh, Pa.	1	B. & W.	32,200
Detroit Edison Co., Detroit, Mich. Trenton Channel Plant.	2	Stirling	31,250
Narragansett Elec. Light Co., Providence, R.I.	2	B. & W.	18,400
	2	B. & W.	20,200
St. Joseph Lead Co., Rivermines, Mo.	2	Heine	10,760
Allegheny Steel Co., Brackenridge, Pa.	2	Stirling	8,660
Penna. Water & Power Co., Holtwood, Pa.	3	B. & W.	15,100
Pejepscot Paper Co., Pejepscot, Maine.	1	Stirling	6,500
Ford Motor Co., River Rouge, Mich.	1	Ladd	28,480
Narragansett Elec. Light Co., Providence, R.I.	8	B. & W.	6,450
Union Elec. Light & Power, Cahokia Stn., E. St. Louis.	2	B. & W.	19,400
Wisconsin Traction Light, Heat & Power Co.	4	Springfield ..	8,430
City of Detroit, Mich Public Lighting Comm.	6	B. & W.	10,200
Archibald Fraser, Madawaska, Mo.	2	Badenhausen ..	6,750
Texas Construction Co., Trinidad, Texas.	4	B. & W.	19,350
Wisconsin Traction Light, Heat & Power Co.	4	Springfield ..	8,410
Cleveland Elec. Ill. Co., Beach Park, Ohio.	4	Stirling	32,900
Metropolitan Power Co., Middletown, Pa.	1	Connelly	15,800
Canadian International Paper Co., Quebec.	4	B. & W.	10,950
Union Elec. Light & Power, Cahokia Stn., E. St. Louis.	2	B. & W.	19,400
Firestone Tire & Rubber Co., Akron, Ohio.	3	Stirling	6,460
Consolidated Gas & Elec. Co., Baltimore, Md.	2	B. & W.	28,500
Comal Power Co., New Braunfels, Texas.	2	B. & W.	19,380
Canadian International Paper Co., Quebec.	3	Long Drum ..	10,950
Southern Power Co., Charlotte, N.C.	4	B. & W.	28,600
Metropolitan Power Co., Middletown, Pa.	2	Connelly	15,800
Mead Pulp & Paper Co., Chillicothe, Ohio.	3	Stirling	11,800
New York Edison Co., New York.	10	Springfield ..	16,650
Milwaukee E.R. & L. Co., Milwaukee, Wisconsin, Lakeside Station.	1	Stirling	30,800
Illinois Power & Light Co., Venice, Ill.	2	Cross Drum ..	16,100
Firestone Tire & Rubber Co., Akron, Ohio.	4	Stirling	9,400
	4	Connelly	19,300
Detroit Edison Co., Trenton Channel Stn.	3	Stirling	31,200

THE TWENTIETH CENTURY FUEL.

Fuel Economy Essential to Industrial Prosperity.

The factor which, perhaps above all others, will have direct bearing on our industrial progress in the next few years will be fuel economy. It is hardly to be expected that in the near future the average cost per ton of crude coal—which is this country's primary and main *source* of heat, light and power—will fall to any considerable extent. How then can the problem be solved ? In one way only—by increasing the efficiency of utilisation of our coal. To increase the efficiency of utilisation of coal we must first of all subject it to scientific treatment in our gas works. There in addition to deriving from it a smokeless solid fuel and many valuable drugs, dyes oils, explosives and fertilisers, we obtain gas—the ideal smokeless fuel for domestic and industrial purposes. Whether gas be used for heat or for power it is conveyed to the point of usage easily and invisibly without adding to our traffic difficulties; it requires no storage by the user; it is always and immediately available for use without laborious preparation; it is practically constant in quality or calorific value; it is under complete control and can be exactly regulated at will; it requires little or no attention while in use; it eliminates stoking; it is clean; it can be shut off and waste can be avoided as soon as the demand for heat or light or power ceases; it therefore saves labour, time and trouble in many ways.

It is a most striking fact, appreciated by few, that there are already some three thousand trades in which gas is employed, actually for an average of no fewer than seven processes in each. Progressive manufacturers are experiencing many benefits and effecting substantial economies by the use of gas instead of crude coal in industrial operations that require heat. The gas industry is always willing to bear its share of the cost of experimental work for manufacturers when it is shown that there is a reasonable prospect of results accruing to the benefit of both parties. Many gas undertakings have therefore fitted up on their premises furnace demonstration rooms. In these rooms there are at the disposal of manufacturers, for testing purposes, various types of furnaces and other gas appliances; a portable pyrometer set is also generally available for recording temperatures. It is thus possible for the manufacturer to ascertain definitely the cost of any class of heat-treatment work before he commits himself to any expenditure. Only by carrying out tests on the actual material to be treated in practice can reliable statistics be obtained. Processes which are secret can with confidence be referred to the technical expert of the local gas undertaking. In his professional capacity as consultant he may be relied upon to guard the secrets of his clients in the same way as a doctor or a lawyer.

Some idea of the magnitude of the service of the gas industry in this country may be derived from the fact that the largest gas supply undertaking in the kingdom alone distributes annually from its works in East London more energy than all the public electricity stations of the country added together. The gas industry steadily expands year after year, serves more and more customers, and adds to the number of industries in which gas is employed. And it is the sure foundation of a number of extensive industries, such as the chemical industry, which finds valuable resources in the by-product derived in the course of gas manufacture.

The new pier at Beckton in East London, the largest Gas Works in the World, showing the largest Coal-handling plant in Europe.

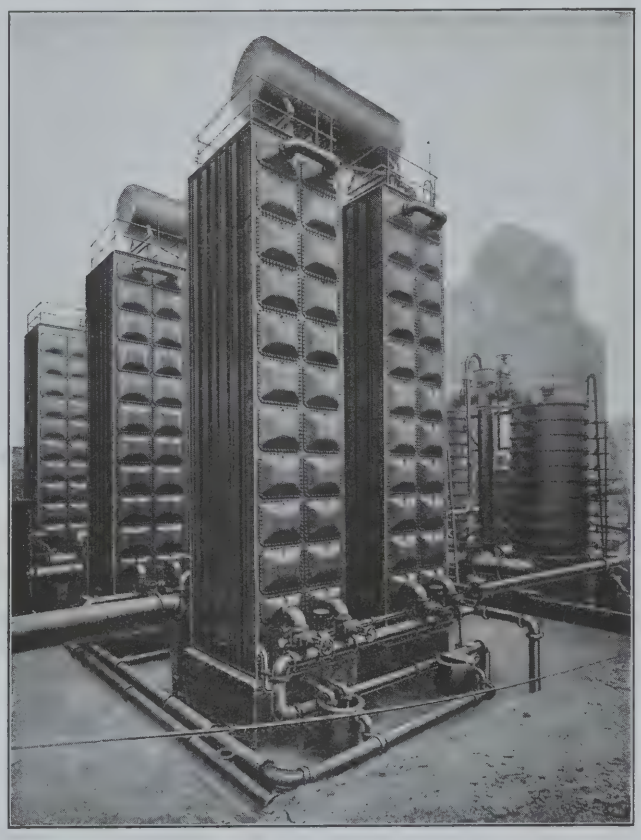
BY-PRODUCT PLANT DESIGN.

The progress which has been made in recent years in the heat treatment of coal for the production of gas and various forms of smokeless fuel has made insistent the demand for improvement in the apparatus employed for the recovery and refining of by-products.

The correct treatment of the crude gas leaving the carbonising unit, including the initial cooling and tar separation, and the recovery of ammonia, oil and benzol in marketable form, requires a careful study of the physical principles involved.

Economy in water consumption, the use of heat interchange devices, and the arrangement of plant to secure low operating costs with the minimum of capital expenditure, are of vital importance, often deciding the success or failure of the complete installation.

THE HOLMES "SUPER TYPE" GAS COOLERS, Patent D/L, and Brush Type Washers for tar, ammonia and benzol recovery, together with a variety of "Continuous" Distilling equipment for refining these products, are the outcome of 75 years' experience, combined with careful research and experimental work carried out under the supervision of a specially trained technical staff.



An installation of Holmes' Semi-direct Type By-product Plant.

W. C. HOLMES & CO., LTD.,

HUDDERSFIELD,

Offer a specialised service in the building and complete equipment of by-product Works.

ESTABLISHED 1850

FUEL EFFICIENCY:

IMPROVING AVAILABILITY.

FUEL EFFICIENCY, apart from "boiler efficiency" or "furnace efficiency," may be defined as its "availability" or capacity for being converted from potential energy into useful, high-temperature heat energy. All fuels, whether solid, liquid, or gaseous, powdered or smokeless, of high or low calorific value, are not, of course, equally efficient; some require more and some less excess air to effect their complete combustion, and, more important, some give greater radiation than others. Their individual efficiency and ultimate commercial value must vary accordingly. Coal usually is allowed 100 to 150 per cent. excess of air.

Fired in suitable circumstances under steam boilers, 14 to 16 per cent. CO_2 is maintained in the flue gases, with gas coke as fuel, indicating the use of only 30 to 50 per cent. excess air. The resulting high furnace temperature gives a corresponding high duty, the average evaporation obtained being 10 lb. per lb. of coke of good average quality.

Another important factor in maintaining efficiency in fuel use is the outlet temperature of the waste flue gases, which, of course, should be as low as possible. To this end, "economisers" are frequently interposed between the boiler-flue outlet and the chimney, in coal-fired boiler plants. The economiser is, in fact, an apparatus the conception of which is due to the very inefficiency of coal as fuel. It is an appliance rarely installed in coke-fired boiler plants, the reason being that the outlet temperatures of the coke-fired boilers, which, compared with those fired with coal, are relatively low, do not, except in special circumstances, warrant the extra cost of installation and maintenance of economisers.

The combustion of coke is a "single stage" process, and being largely localised and completed at a high temperature within the furnace area, the transmission of heat to the water and steam inside the boiler is effected mainly by direct radiation, and is therefore more complete and effective than that obtained with long flaming coal. The relatively low outlet temperature obtained in practice when coke exclusively is used as fuel tends to prove this theory.

In 1913 the London Coke Committee was established to promote the use of gas coke for fuel purposes by means of actual demonstrations on steam users' boiler plants. One result of their efforts in this direction has been to extend the use of coke to the largest power stations, factories and institutions, entirely upon its merits and economic advantages; and the Committee are at all times pleased to offer the assistance of their free expert advisory service on all questions relating to economical power production and central heating.

Requests for appointments should be addressed to:—

THE SECRETARY, THE LONDON COKE COMMITTEE,

84, Horseferry Road, S.W.1.

Telephone:—Victoria 8100.
Extension 81.

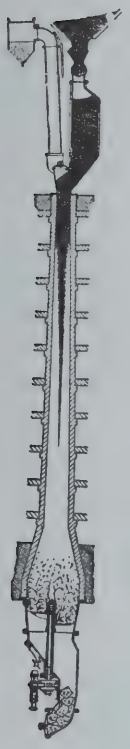
MAXIMUM GAS YIELD

means

FUEL ECONOMY.

THE GLOVER-WEST SYSTEM OF CONTINUOUS CARBONISATION

produces the maximum thermal yield of gas and output per ton of coal.



COAL IN THE GLOVER-WEST SYSTEM continuously descends by gravity through retorts which are elliptical in section and designed for the easy passage of all classes of coal.

The speed at which coal passes through the retorts is easily controlled to ensure correct carbonisation.

WATER-GAS AND COAL-GAS are simultaneously produced in Glover-West Retorts which are surrounded by horizontal combustion chambers, the temperature of which is controlled throughout the length of each retort to ensure efficient carbonisation of the coal and water-gas manufacture, the steam for which is generated by waste-heat from the plant.

The remarkably high efficiency of water-gas production in the Glover-West Retorts is due to the maintenance of the required temperature in the zone of reaction, economy of coke and minimum labour operations.

EXHAUSTIVE TESTS ON GLOVER-WEST PLANTS by:—

H.M. Fuel Research Board,
The Gas Investigation Committee of the Institution of Gas Engineers,
and in many Installations in all parts of the World

prove the value of the Glover-West System in assisting to solve Britain's Fuel Problems.

WEST'S GAS IMPROVEMENT COMPANY, LTD.,

Engineers,

MILES PLATTING ——————————— **MANCHESTER.**

LONDON :
Regent House, Kingsway, W.C.2.

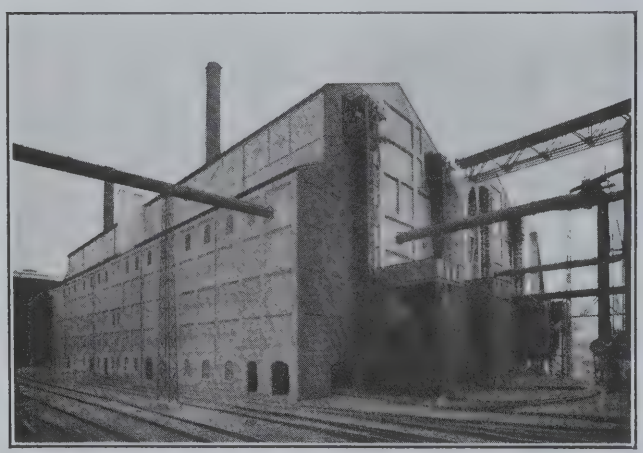
AUSTRALASIA :
Union House, 243, George Street, Sydney, N.S.W.

NEW YORK :
West Gas Improvement Co. of America, Inc.,
441, Lexington Avenue.

PARIS :
Cie. Gle. De Construction de Fours, 8, Place des Etats-Unis,
Montrouge (Seine).

CARBONISATION

The problems facing the Gas Engineer of to-day are infinitely greater than those of 30 years ago. With the speeding up in industry and the necessity for reducing costs of production all round, there have been enormous developments in the methods employed in the production of Town's Gas.



W-D CONTINUOUS VERTICAL RETORTS.

The question which each Gas Engineer puts to himself, when having to make his plans for increased production or for renewals of plant, is " What type of carbonising plant will enable me to reduce the cost of production of gas under my particular local conditions of coal supplies and markets for my products ? "

Very few undertakings are alike in this respect, and it is not practicable to standardise the requirements of Gas Engineers.

Undertakings situated long distances from the sources of coal supply frequently find it pays to buy the highest qualities and the best grades.

Other undertakings closely situated to the Pit Mouth can, with advantage, buy lower grades of cheap coals—very often slacks—which it would not pay to carry long distances.

Some undertakings have a ready outlet for all the coke they can produce; others, because of local conditions, find great difficulty in selling their full make.

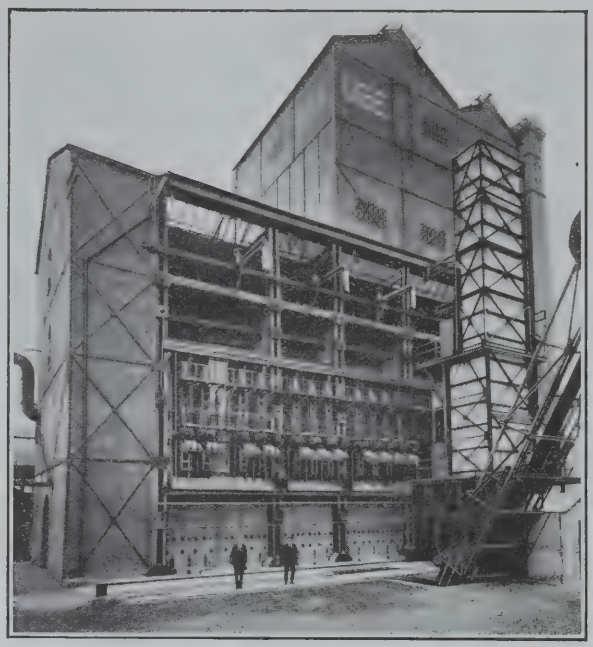
Under these conditions, it is essential that Engineers should have at their disposal a selection of Carbonising Systems which will enable them to choose the one which will best satisfy their requirements.

W-D INTERMITTENT VERTICAL CHAMBERS.

In one case it may be CONTINUOUSLY WORKING VERTICAL RETORTS, which give a high thermal yield per ton of coal and per unit of ground space, combined with a first-class Domestic Coke and low Labour costs per therm made.

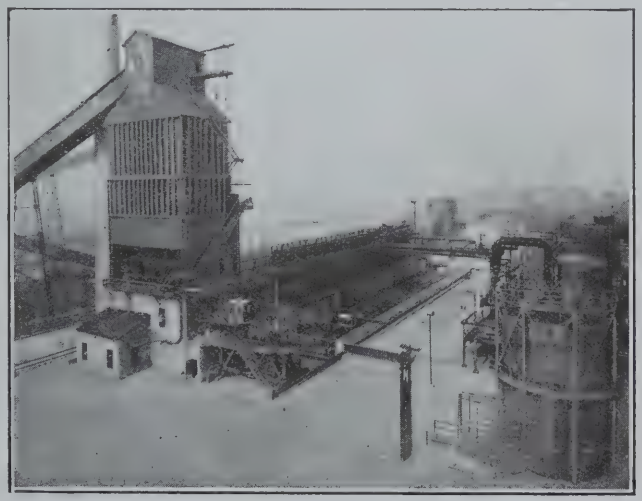
CARBONISATION (continued).

On the other hand, INTERMITTENT VERTICAL CHAMBERS may suit the conditions of a smaller works best. In these plants it is possible to use any class of coal, particularly cheap slacks, and produce a dense coke suitable for domestic purposes when properly screened, but more suitable than Continuous Vertical Coke for industrial furnace work. These plants occupy much less ground space than Horizontal Retorts, require less labour, and will give a satisfactory thermal yield per ton of coal.



W-D INCLINED CHAMBERS.

On larger works, the conditions holding for Intermittent Verticals may, with advantage, be obtained from either INCLINED CHAMBERS or from COKE OVENS of such sizes and dimensions as will best suit the size of works on which they are installed. Chamber Ovens occupy less ground space than Coke Ovens, but in every respect are similar in the results they will give.



BECKER COKE OVEN.

The Woodall-Duckham Companies are in a position to supply any of these systems, and so meet the particular requirements of the individual Gas Engineer. Impartial advice can be given by Technicians having an invaluable experience of all Carbonising Systems, this experience being backed up by sound design, materials of the highest quality, and a Constructional Organisation capable of handling any demands that may be made upon it.

For further information apply to—

THE

WOODALL-DUCKHAM VERTICAL RETORT AND OVEN CONSTRUCTION CO.

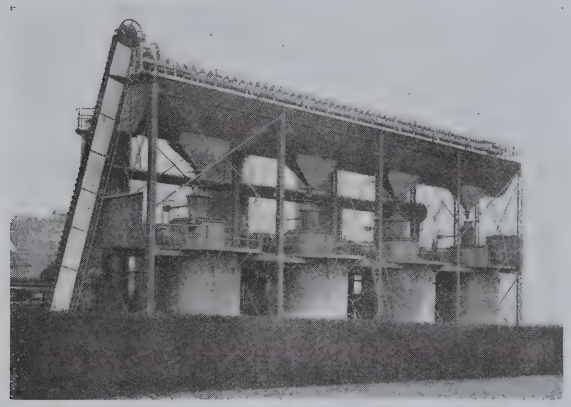
(1920), LIMITED,

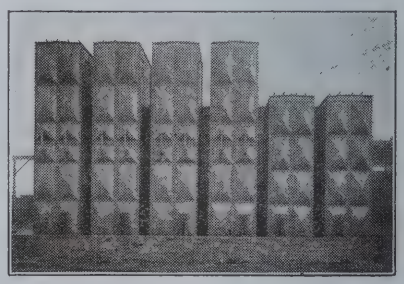
ALLINGTON HOUSE, 136, VICTORIA STREET, LONDON, S.W.1.

GASIFICATION OF COAL.

Expert Assistance in Construction of Plant.

When the installation of new Plant is contemplated or decided upon, a question of the first importance is: Who is to undertake the manufacture of it? There are, of course, plants of standard designs with relative merits for certain kinds of processes, but, on the other hand, where new projects are involved or plants of a unique type, the co-operation of a manufacturing firm of experts with the requisite experience is essential. For instance, in the case of an installation of Process Plant, for which the inventor or designer has not manufacturing facilities, it may be necessary for the buyer to assume certain responsibilities for making manufacturing arrangements. Much trouble and expense may often be avoided if the work is entrusted to a firm of contractors who, out of their experience in the manufacture of analogous types of plant, are able not only to construct apparatus to the drawing furnished, but to act as guide, counsellor and friend in regard to the many practical questions that arise during the course of construction, the co-ordination of the various units, and the assembling of the whole to work satisfactorily. Such service calls not only for a considerable degree of engineering skill, but for technical knowledge of the problems involved. It is rarely that such a combination can be found except in those who have accumulated experience through being continuously engaged in the design and manufacture of Plant, and whose business it is to keep abreast with modern developments. An outstanding example of a concern able to offer such service is found in Messrs. ASHMORE, BENSON, PEASE & CO., LTD., of Stockton-on-Tees, who have large Works equipped with the most modern facilities, including Laboratories, and a trained staff expert in design, construction, and erection of Gas, Chemical, Metallurgical, and Carbonaceous Fuel Plants. That their efforts have met with a large measure of success is evidenced by the variety of work they have done for many of the leading Industrial Concerns, Municipal Bodies and Government Departments, at home and abroad. The illustrations shown hereon are typical examples of their work.





In the past few years a notable advance has been made in engineering science by the production of steels capable of withstanding the corrosive action of acids, and, henceforth, vessels constructed of such materials will be a feature in most programmes for extensions to, or renewals of, existing plants. In the fabrication of such steels, the safeguard of experience, already commented upon, should be secured, and, in this connection, Messrs. ASHMORE, BENSON, PEASE & CO., LTD., have had an extensive and successful experience.

Telegrams:
"Gasholder, Stockton-on-Tees."

Telephone 501.

ASHMORE, BENSON, PEASE & CO., LTD.,

Associated with

THE POWER-GAS CORPORATION LTD.,

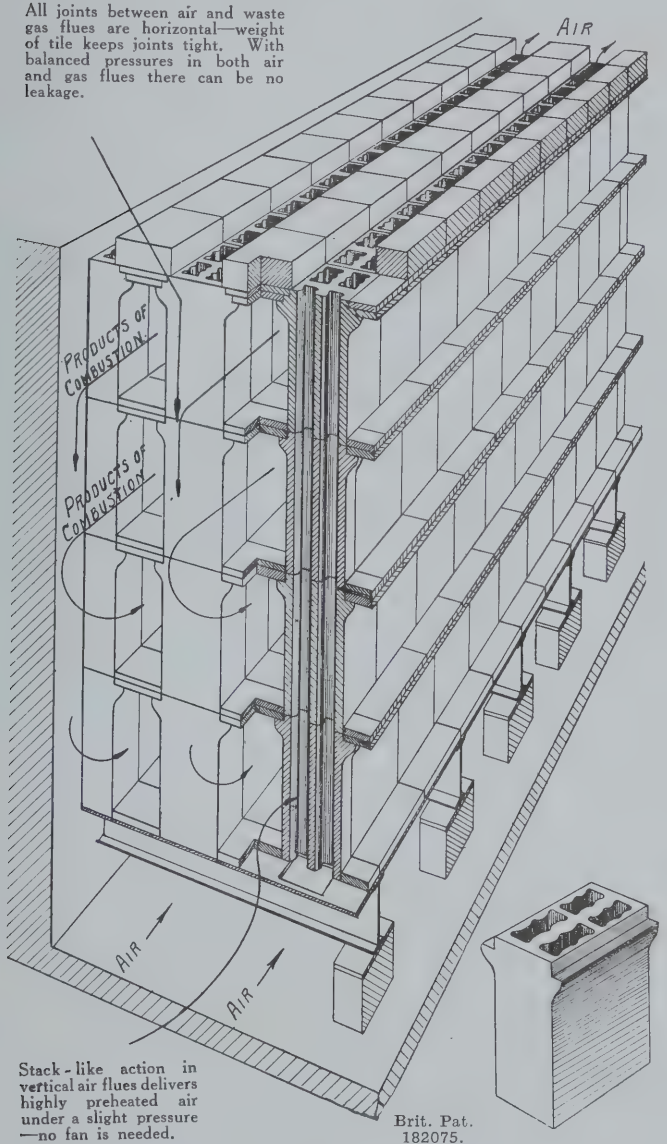
PARKFIELD WORKS, STOCKTON-ON-TEES

London Office:
39, Victoria Street, Westminster, S.W. 1

RECUPERATION FOR

Industrial Producer Gas-Fired Furnaces.

Probably the most important consideration in the design of this class of furnace is the method adopted for the preheating of the air for combustion.



All joints between air and waste gas flues are horizontal—weight of tile keeps joints tight. With balanced pressures in both air and gas flues there can be no leakage.

Stack-like action in vertical air flues delivers highly preheated air under a slight pressure —no fan is needed.

Brit. Pat. 182075.

In a few cases thermal requirements call for Reversing Regenerative Furnaces when usually both the air and gas are preheated before combustion takes place, but in a very wide range of industrial furnaces "Continuous" Recuperation is by far the better method of preheating the air and also if necessary the gas.

A correctly designed Recuperator must:—

(*a*) Operate on natural draught, no fan is necessary or desirable.

(*b*) Remain free from leakages and require no repair over many years of working.

(*c*) Provide for the maximum heat being recovered from the waste gases.

The Stein System of Recuperation has been installed on more than 3,000 Industrial Furnaces of different types including the following:—

Rolling Mill Reheating Furnaces of all types.

Forge Furnaces working in conjunction with Hammers and Presses.

Steel, Iron and Non-Ferrous Annealing Furnaces.

Case Hardening Furnaces.

Glassworks Furnaces.

Caustic Pot Settings, etc., etc.

In all such cases the highest possible thermal efficiencies coupled with maximum outputs and accuracy of control CAN BE GUARANTEED.

STEIN & ATKINSON, LTD.,

47, VICTORIA STREET, LONDON, S.W.1.

Telephone: Victoria 7325 and 7326. **Telegrams: Metasteina, Sowest, London.**

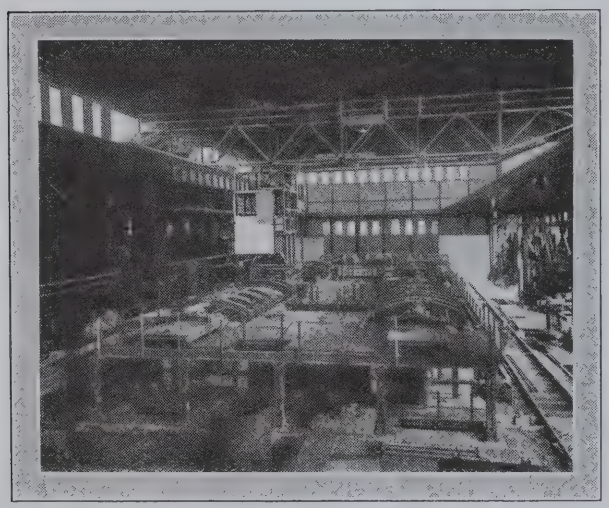
ALLIED FIRMS in France, Belgium, Italy, Spain, Germany, U.S.A.

STEELWORKS EQUIPMENT.

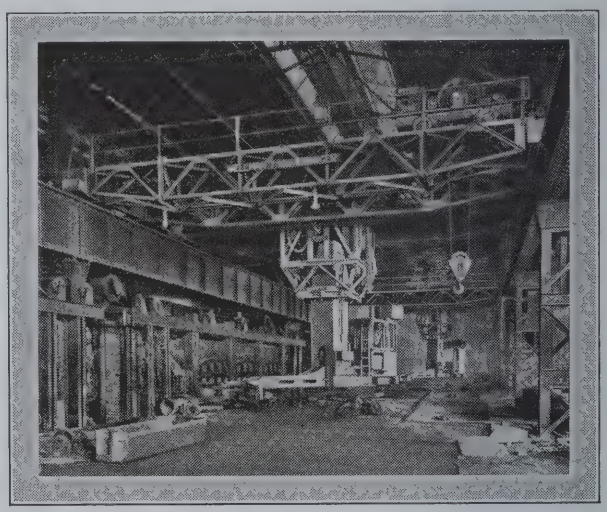
The manufacture of open hearth steel has made rapid progress during recent years, largely due to the great improvements which have taken place in the design and construction of Steel works Equipment.

Many of these improvements have been inaugurated by The Wellman Smith Owen Engineering Corporation, Limited, whose machines may be seen in most of the steel works in this country and on the Continent.

Their latest Gas Machines, the type "L," have proved themselves to be the most reliable and efficient machines yet produced for dealing with the various qualities of coal obtained in all parts of the world. They are built in sizes to gasify from 2,000 to 5,000 pounds of coal per hour. Their Hot Gas Efficiency is over 93 per cent. In many instances, in replacing other types, they have reduced coal consumption from 15 to 50 per cent.



10-ton Vertical Ingot Charger and Soaking Pits.



Two 7-ton Slab Charging Machines and Reheating Furnaces.

In the British Isles alone, their Fixed Open Hearth Furnaces have a total productive capacity of over 1½ million tons of steel per annum. In some instances the coal consumption is as low as 4 to 4½ cwts. per ton of ingots produced. They have also constructed Active Rolling Furnaces from 30 to 250 tons capacity and Active Metal Mixers up to 750 tons capacity. The largest Rolling Furnaces are producing 2,000 tons of ingots each per week.

A notable installation is the 1,000-ton capacity Hot Metal Mixer recently erected at the works of the Ougree-Marihaye Company in Belgium. This Mixer passes on an average 1,700 tons of iron every 24 hours, and also melts cold mild steel scrap at the rate of 2,000-3,000 tons per month.

Their gas-fired Ingot Soaking Pits, patent Continuous and Wash Heating Furnaces working in many of the Steel Works in Britain and on the Continent are giving efficiencies that cannot be beaten. Some of their Continuous Furnaces are heating steel billets from cold to a rolling temperature with coal consumptions ranging from 1 cwt. to 1½ cwts. per ton.

The experience accumulated by an expert staff, during many years' practice in all the steel-producing countries of the world, is available to anyone interested in the layout of complete Steel Plants or the improvement of existing heating arrangements.

The Wellman Smith Owen Engineering Corporation Limited,
VICTORIA STATION HOUSE, LONDON, S.W.1., and DARLASTON, S. STAFFS.

Constant Pressure Steam Accumulation

(KIESSELBACH SYSTEM).

The constant pressure steam accumulator now made in the United Kingdom by the Aerogen Company, Limited, under sole license for the British Empire from Dr. Kiesselbach, stores steam during periods of low demand and gives it back to the steam system during periods of high demand. Boilers are thereby able to operate under the best firing conditions and on an average load with no loss of steam through the safety valves; no drop in pressure is necessary between the delivery of the steam to the accumulator and its re-delivery to the steam system—the steam is supplied at all times at constant pressure and without loss of superheat. The system is simple, entirely automatic, and in the large number of installations made no failure has occurred.

Owing to the increased circulation which takes place within the boilers better condition of tubes and boilers is obtained and the deleterious effect of bad feed water is considerably decreased. As the feed is delivered from the accumulator at boiler pressure and temperature no "lag" occurs in the heating up of the normal cold feed in order to obtain steam, and boilers can, therefore, be rapidly placed into commission.

The Aerogen Company will also install a combined constant pressure and variable pressure accumulator to meet the requirements of works where boilers are required to be damped down and quantities of low-pressure steam are needed.

The following are extracts of testimonials recently received:—

COLLIERY. (1) 10 per cent. increased boiler efficiency; only two boilers used instead of three.

(2) 33 per cent. reduction in heating surface. Perfect equalisation.

(3) Non-fluctuating working pressure under extremely fluctuating supply and demand of steam.

LEATHER WORKS. Fuel saving 10 per cent.; pressure used to drop to 75 lbs., but now maintained at 150 lbs. per square inch; stoppages for boiler cleaning less frequent; several boilers taken out of use since coupling in accumulator.

STEEL WORKS. Accumulator allows 60 per cent. additional steam supply for peak periods.

DYEING WORKS. Two boilers found unnecessary; fuel saving considerable; constant steam pressure; factory production increased by 10 per cent.

ELECTRIC POWER AND TRAMWAYS. Working expenses 6 per cent. lower.

The Company will be pleased to supply descriptive literature and submit schemes to suit the conditions at any particular works.

THE AEROGEN COMPANY LIMITED,

36, BOLSOVER STREET, GREAT PORTLAND STREET, LONDON, W.1.

Telephone: Museum 7078. Telegrams: Aerogen Eusroad London.

BOILER HOUSE INSTRUMENTS.

Modern systems of combustion show as great an advance over the old as the locomotive of to-day shows over the former efforts of George Stevenson.

The old idea of a furnace may have " looked " hot, but, in the struggle for more and more efficiency, the eye was soon found to be unreliable.

Instruments were essential for indicating and recording the flow of steam, air and feed water, as well as temperatures of steam, waste gases and coal consumption.

The high price of fuels suitable for steam generation has caused steam users to study closely the various methods of effecting increased boiler efficiency, and, therefore, instruments suitable for boiler-house use have now become recognised as essential items in power plant equipment and many are the various types now available; of these, the Bailey range of Indicators and Recorders are being extensively adopted.

Of special interest to those who study combustion conditions is the Bailey Boiler Meter which records on one chart the steam generated by the boiler and the air supplied for combustion. The instrument is so arranged that when the two pens are co-incident the boiler attendant can tell at a glance that the correct amount of air is being supplied to suit the load at which the boiler is working.

This instrument is calibrated at site by a combustion engineer who decides what percentage of excess air is necessary, after running tests and making an examination of the CO_2, draught and temperature.

The simplicity of the records and the manner in which they are given appeal to the boiler attendant, and, invariably, results are obtained by this method superior to those obtained with other types of combustion apparatus.

Proper control of the air supplied for combustion is now being recognised, and it is safe to say that in the near future air will be supplied to boiler furnaces as carefully as steam is now supplied to turbines.

Temperature indicators and recorders are also necessary items in the modern power plant, and in this direction much has been done to design apparatus entirely suitable for boiler-house use and those now offered have little resemblance to the earlier types which were far more suitable for the laboratory. Temperature bulbs extending the full width between the boiler walls are now used, as it is recognised that the true average temperature of the escaping gases cannot be obtained by short bulbs no longer than five feet; when it is remembered that modern boilers are anything from twenty-five to thirty feet in width, it will be seen that the long bulb is a necessity, and the Bailey Temperature Recorder has been designed to meet such conditions.

The Bailey Boiler Meter can be arranged to record on one chart the steam flow, air flow and flue gas temperature. Further, a record of the steam temperature can also be added so that the full " story " of the boiler operation is presented in a compact form.

Draught measurement has also received close attention, for whilst in the old days engineers were satisfied with instruments reading to within $\frac{1}{8}$in. W.G., indicators to-day are made to operate in steps of 1/100 of an inch.

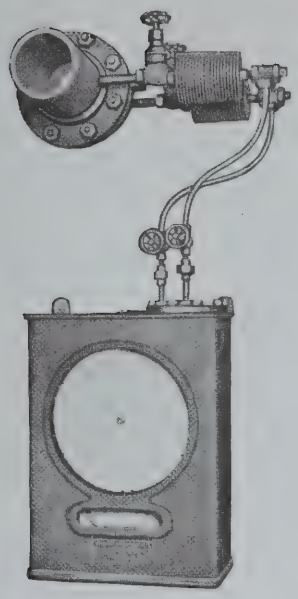
To establish the performance of economisers and air heaters, instruments are also available. These are arranged to record, on the same chart, temperatures of feed water entering and leaving the economiser, as well as the temperature of waste gases entering and leaving. Air heater temperatures are obtained in a similar manner.

Automatic boiler control, now no longer an experiment, is being installed in a number of power plants where pulverised fuel has been adopted, and in this direction the Bailey system has achieved remarkable success. One of the latest to be installed is at the Congella Power Station, Durban, South Africa, which plant is fired by means of the " Lopulco " system of pulverised fuel.

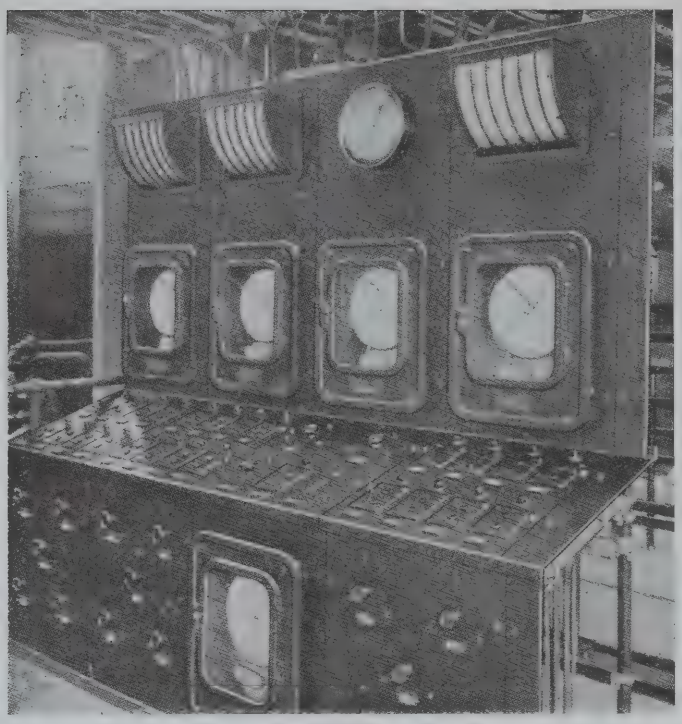
It will be seen, therefore, that the importance of combustion is now recognised and guess-work methods are being entirely eliminated; the use of Bailey meters can be extended to your own plant, whether modern or old, and, if the latter be the case, results can be secured which will amply repay the expenditure incurred by the adoption of instruments.

There is at your disposal a staff of experts who will gladly advise as to the type of apparatus best suited to your particular needs.

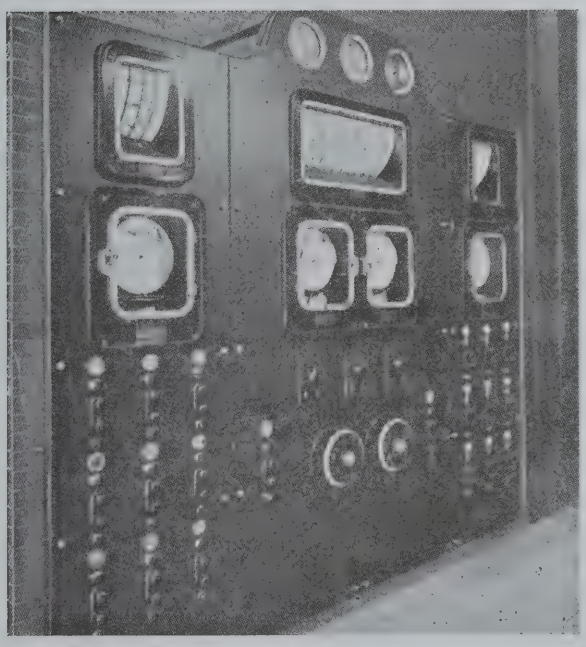
On the opposite page, typical installations of control panels are given, and it will be seen from their appearance alone that boiler control is now a science which displaces the uncertainty of the human element and replaces it with apparatus which will ensure efficient operation.



Bailey Steam Flow Recorder.



Control Panel for Four Boilers, installed in a large Generating Station.



Control Panel arranged for Automatic Boiler Control.

BOILER CONTROL APPARATUS.

INSTRUMENTS FOR INDUSTRIAL PLANTS

STEAM, WATER, AIR AND GAS METERS

DRAUGHT GAUGES AND GRAVITY RECORDERS

TEMPERATURE MEASUREMENT.

Your enquiries are solicited and Catalogues descriptive of the above can be obtained on request to the leading specialists.

Industrial Combustion Engineers, Ltd.

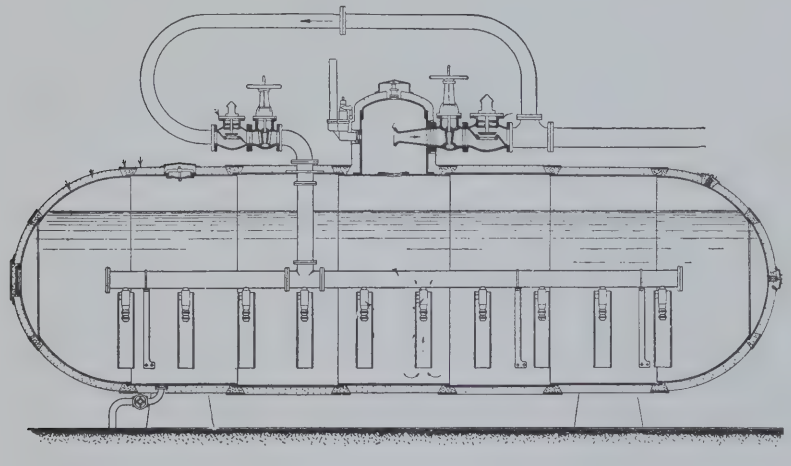
31-37, WYBERT STREET, LONDON, N.W.1.

THE RUTHS STEAM ACCUMULATOR SYSTEMS

Many factories throughout the world are benefiting by the manifold advantages to be obtained from the RUTHS STEAM ACCUMULATOR. Over 350 Plants have been installed, of which a fair proportion is in Britain.

This is the only system which governs the steam flow to the factory, controls the working steam pressures throughout, and is capable of supplying steam at a practically unlimited rate. The steam reserve is instantly available as the latent heat required for its formation (some 70 per cent. of the total heat in the steam) is not dependent upon the burning of fuel in the boiler grates, but is drawn from the potential heat energy in the accumulator. There is thus no time lag in meeting peak loads. Moreover, the Ruths System is applicable to boiler houses where economisers are fitted. The constant flow of water through these units together with the constant rate of firing and constant temperature at the chimney base result in a boiler plant which is easily controlled, and can maintain a consistent efficiency of the highest order.

As there are few industries where working pressures of at least two orders are not required, the RUTHS VARIABLE PRESSURE ACCUMULATOR has an almost unlimited field of application and offers the following advantages :—



Automatic control of steam to all departments.

Instant availability of steam at all times, and at any required rates.

Fuel saving 15—25 per cent.

Boiler capacity reduced 30 per cent. to 50 per cent.

Decreased overhead and running costs.

Increased production and improved quality of manufactured article.

Where difficulties in providing a suitable range of pressure for this system prevent its application, the RUTHS CONSTANT PRESSURE ACCUMULATOR offers the best alternative. In this system all surplus steam generated by the boilers during periods of light demand is allowed to overflow past a Ruths Control Valve to the accumulator, where it is condensed by the addition of sufficient cold feed water. This water is heated up to saturation temperature, and is drawn upon for boiler feed purposes during periods of peak loads. This system involves no variation in the superheat temperature or the flow of water through the economisers.

There is also a RUTHS COMBINED STEAM AND FEED WATER ACCUMULATOR where the factory conditions are such that neither the steam or feed water accumulators alone could wholly equalise the boiler load.

Detailed schemes may be obtained upon application to the sole licensees and manufacturers for the British Empire (Canada excepted).

FAIRFIELD-HOWDEN RUTHS STEAM ACCUMULATORS, LIMITED,

Head Office :—**195, Scotland Street, GLASGOW.**

Registered Office :—**Caxton House, Westminster, LONDON, S.W.1.** *Branch Office* :—**86, Cross Street, MANCHESTER.**

METERING AND BOILER FEED, STEAM, OIL, &c.

The modern tendency to control scientifically the consumption of fuel has resulted in the rapid development of Fluid Meters in boiler and engine houses, collieries, and indeed any factory which uses steam or compressed air.

A comprehensive range of such Meters is marketed by GEORGE KENT, LTD., of London and Luton, who have specialised in metering apparatus for the past 35 years.

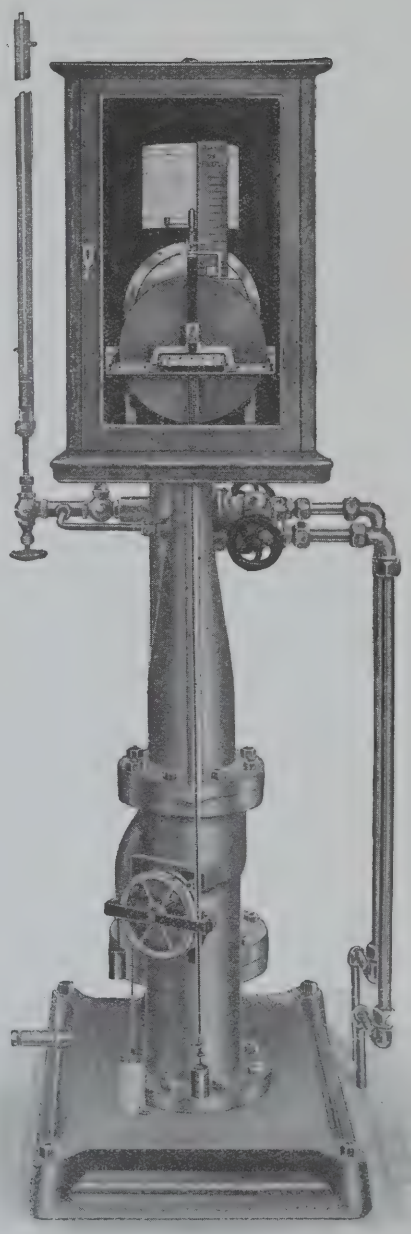
For Boiler Feed and Condensate, the Kent Venturi Meter will successfully measure the discharge, no matter what its characteristics may be, with the minimum loss of head. The Recorder gives, in addition to the total quantity reading, a diagrammatic record of the flow.

Steam Meters can be supplied in a variety of patterns suitable for metering boiler output, turbine consumption, process steam, etc. Individual steam records are made with characteristics most suited to the work they have to perform. Pressure-correcting, electrical distance recording, diagram and indicating are a few of the patterns manufactured.

The range of Oil Meters is likewise sufficient for all industrial requirements, and Meters can be supplied for measuring either bulk supplies or oil fuel supplies to individual burners.

Gas Meters, Air Meters, Petrol Meters, Service Water Meters, Testing Apparatus, are further examples of industrial instruments.

The numerous types offered make it possible to select a meter ideal for any particular job, and on receipt of particulars GEORGE KENT, LTD., will be glad to offer suggestions for overcoming any metering problems which have given occasion for thought.

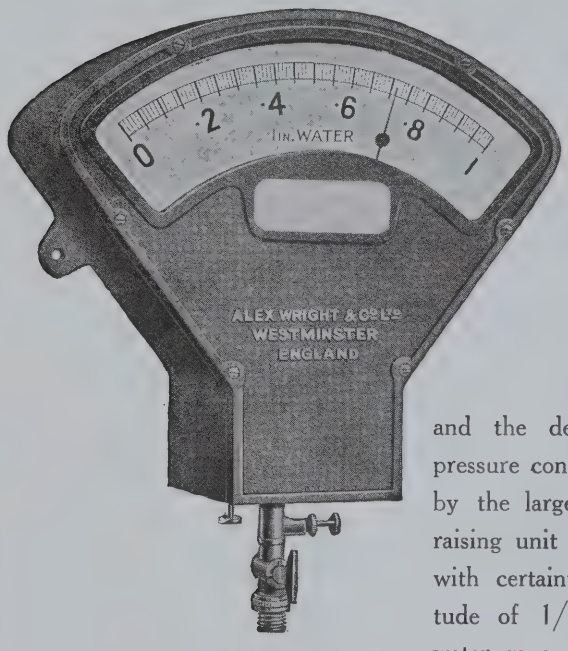


George Kent Ltd
LONDON & LUTON

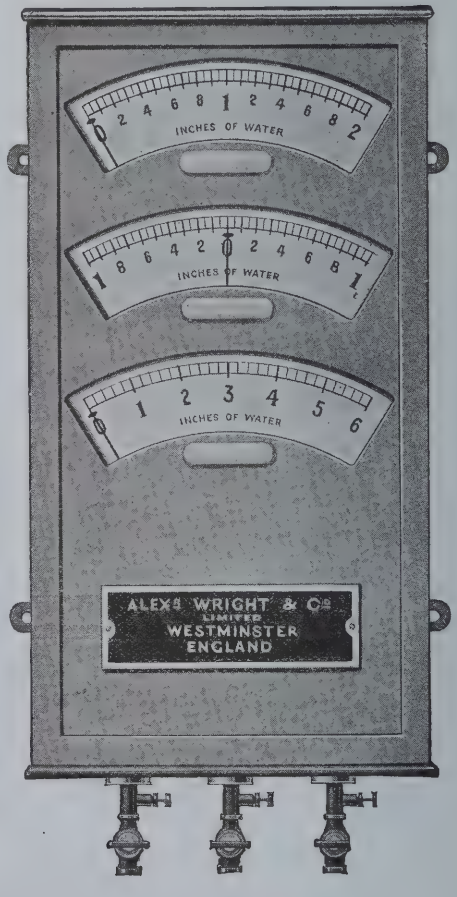
BISCOT ROAD WORKS, LUTON, BEDS.

THE IMPORTANCE OF WORKS CONTROL.

UNDOUBTEDLY one of the most important problems in the Utilisation of Fuel is that of acquiring reliable information on the performance of plant, and the value of indicating and recording instruments for Works Control is now more fully appreciated than was formerly the case. As an example, modern engineering demands a more sensitive and more finely-divided scale upon instruments for indicating draught and pressure than had the water-tube gauge.



In the average boiler house of a few years ago it was considered "good enough" if the dampers were adjusted to a chalk mark, or the draught on a U-gauge showed "somewhere about" one or two inches; but to-day, in the light of more scientific knowledge, correct air regulation is recognised as the only basis on which to build up combustion efficiency, and the delicately balanced pressure conditions demanded by the large modern steam-raising unit must be adjusted with certainty to an exactitude of 1/100th in. of the water gauge.



To meet these requirements we have extended the scope of the well-known Simmance Patent Dead Beat Draught Indicators so that 1/100th in. water gauge is easily discernible over a full-scale range of 0—1 in. water gauge. These fine indications being dead-beat and produced without use of liquid, enable variations of pressure to be determined with perfect accuracy and at a glance. Provision is made for damping down oscillations, venting to atmosphere, and zero-adjustment.

For "balanced draught" systems, or when pressure at various points must be known, as in the modern compartment stoker, these Indicators can be supplied mounted in one case, suitably labelled, as shown by illustration at right, thus bringing the whole pressure system under observation instantly. Being neat and compact this arrangement of units effects considerable saving in space on the control panel.

ALEXANDER WRIGHT & COMPANY, LIMITED,
WESTMINSTER - - - - LONDON, S.W.1.

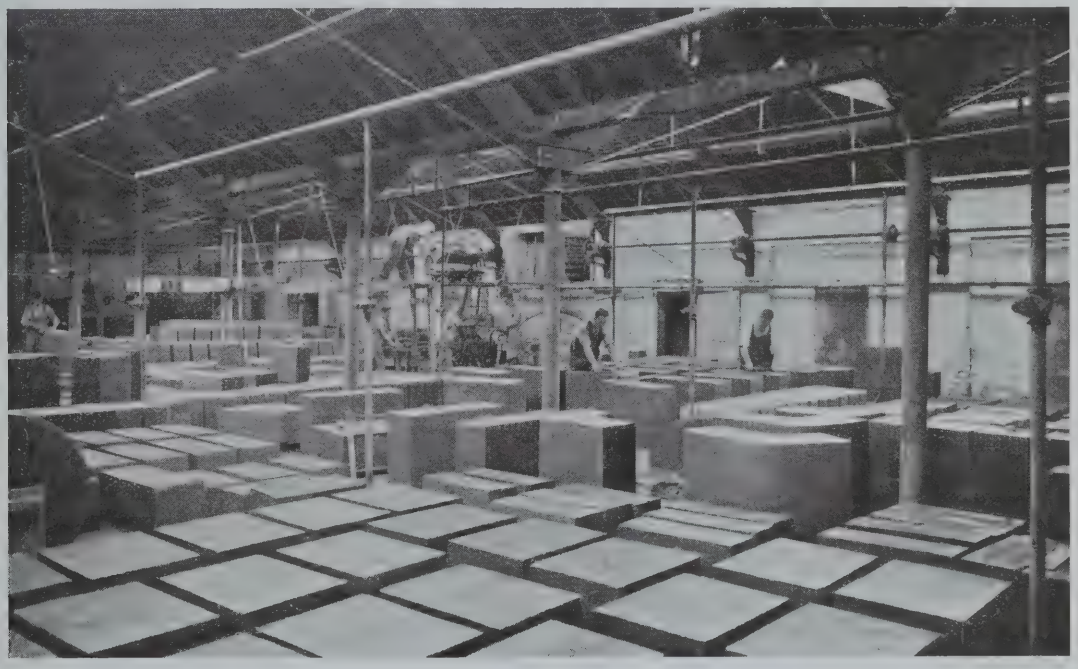
FIREBRICKS FOR GENERAL PURPOSES.

Modern conditions in furnaces of all kinds are far more severe than they were fifty or more years ago, and methods of making firebricks which were excellent in the last century have had to be modified in many ways to enable bricks to be produced which will be durable in present-day work.

To obtain the maximum service from firebricks and the like, it is unquestionably essential to have thorough co-operation between the user and the manufacturer. The user should supply the fullest particulars of his requirements to the maker; he should point out any specially difficult conditions, state the parts of the furnace or other structure where wear and tear is greatest and should, in the frankest possible manner, put the manufacturer in possession of all the facts. Different conditions of working call for such great differences in the composition and properties of firebricks that only by this ample co-operation can the best results be secured.

A large firm of firebrick manufacturers can supply bricks and blocks of many shapes and sizes and with nearly as many different properties. Differences in physical texture and structure which would not be noticed by most users will make enormous differences in the durability of the bricks under various conditions of service, so that it is of the utmost importance that the manufacturer should be definitely informed as to the conditions his bricks are required to meet in any given furnace.

The Stourbridge Fireclays have so long been famous for their resistance to heat and for their suitability for the manufacture of firebricks for general as well as special purposes, that most people think of Stourbridge whenever they need firebricks.



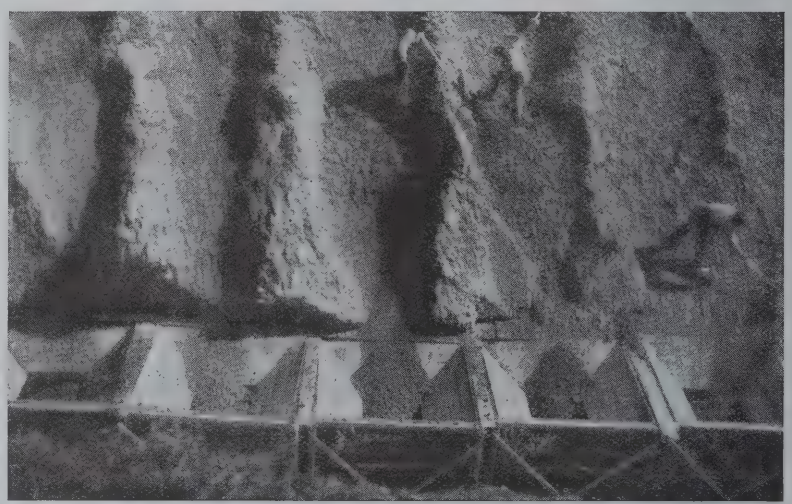
Making Tank Blocks.

The illustration shows a part of an up-to-date works making tank blocks. Great strides have been made in this department in recent years, especially in the use of cells for souring the clay, in a greater knowledge of the effects of grog of different sizes and of details in manufacture.

E. J. & J. PEARSON, LTD., STOURBRIDGE, have one of the largest works in the Stourbridge area; they are fully equipped for making firebricks, retorts and other refractory materials, either for general purposes or to meet the special needs of customers.

INSULATION AS A MEANS OF FUEL ECONOMY.

In engineering practice there are two classes of waste; one is termed unavoidable, the other avoidable. The former becomes transferred to the latter as soon as science discovers a method or material capable of preventing the particular loss incurred. Probably the greatest source of loss under the second category is that of escaping heat which has not carried out the work for which it was generated. The loss of heat through furnace walls is one not readily calculable, and in the majority of cases is disregarded or regarded as an unavoidable loss. From a technical point of view this is not a correct definition, for the reason that there now exist methods and materials capable of preventing the heat from escaping unutilised.



Natural deposit of Diatomaceous Earth on the Island of Fur, shewing method of working.

In these days, when higher temperatures than hitherto are entering into modern practice and the price of coal is high, the necessity for curtailing or eliminating heat losses is urgent. This point was emphasised in a paper recently read before the Ceramic Society, by S. E. Josi and A. E. Hubbard, in which it was remarked that "It is a well-known fact that radiation losses from heated equipment increase very rapidly with increase in temperature; in fact, as the fourth power of absolute temperatures. It is, therefore, increasingly important to prevent heat losses at the higher temperatures." The authors then referred to the means taken to reduce radiation, first by constructing thicker walls and then by the so-called "dead air space." These methods, however, failed, and it is now a generally accepted fact that the only satisfactory method of reducing heat losses through the walls of any high-temperature equipment is to install as a component of the wall a layer of the material having a low thermal conductivity and a lower specific heat.

Loss reduction by insulating.

The practical results attained by the adoption of insulating material are quoted by the authors. In most cases they remark "The substitution of a 4½in. course of insulating brick for a course of common bricks in furnace walls will cut down the loss by from 65 to 70 per cent. Assuming a furnace operating at 990° C. (1.800° F.) (temperature of air 21°C.) (70° F.) with walls constructed of 9 inches of firebrick and 8 inches of red brick, taking the conductivities of the various components at their approximate mean temperatures, we find a conductivity of 552 B.Th.U.'s per sq. ft. per hour. If, on the other hand, the wall were composed of 9 inches firebrick, 4½ inches of insulation brick, and 4½ inches of red brick, the heat loss would be only 189 B.Th.U.'s per sq. ft. per hour.

In other words, without increasing the total thickness of the wall, the heat loss is cut down to 66 per cent. from that of the insulated construction.

Properties of good insulating material.

Air or gases are recognised as the best heat insulators next to a vacuum, provided they can be kept in a quiescent state. This can be brought about theoretically by solidifying the air or gas, or by dividing

the air into minute sealed cells. Nature has, however, provided a material which possesses the peculiar property of a minute air cell structure which is known under the names moler, fosalsil, fossil meal, kieselguhr and diatomaceous earth. It consists of minute silica fossil shells, or diatoms composed of still more minute cells, each separately sealed. As these diatoms are invisible until placed under a powerful miscroscope, one can realise that such a substance must have great qualities of insulation.

View of the Manners Pit on the Island of Fur.

By utilising insulating slabs or bricks made of this material, very good economies in fuel can undoubtedly be effected, and as we have previously stated, in some cases it has been computed that as much as 65 per cent. to 70 per cent. heat lost can be prevented by this means.

It is when the raw material is subjected to microscopic examination that the reason for its insulating properties becomes apparent. This diatomaceous earth is at once seen to consist almost entirely of fossil remains of cellular structure, a physical characteristic which persists unimpaired during subsequent manufacture.

The raw material—from which "Fosalsil," the name under which Moler products are supplied—is a deposit of the ice age, fossil remains of cellular structure rich in diatoms composed of still more minute air cells, each separately sealed by nature. It is the air content of these minute cells which give it its remarkable insulating properties. Not only does it consist of diatome silica, but it has sufficient natural alumina to bind it together. It is, therefore, much superior to kieselguhr, infusorial earth and other fossil meals requiring the addition of some foreign clay to hold them together, which of course is not an insulating material. It possesses great mechanical strength, and tests have proved that even a hollow partition block of "Fosalsil" has a crushing weight of 64.6 tons per square foot (half a ton per square inch). In addition, this material is practically indestructible by fire, as has been proved by a very severe test.

Transporting and loading up raw material at the Island of Fur.

The basis of this new insulating material, "Fosalsil," is the natural product known as moler, which is obtained from extensive stratified deposits occurring on an island off the coast of Denmark. These deposits are owned exclusively by a British company, and are shipped direct to Colchester, the site of the newly installed works. These works inaugurated a new section of the refractory industry, in so far as the sources of the raw material are owned

exclusively by a British company, Moler Products, Ltd. An inspection of the works indicated clearly that from the economic and efficiency point of view they had been designed and equipped in the best possible manner.

Unloading raw material at Colchester.

They are designed for the manufacture of insulating bricks and compositions, sound-proof, fire-proof, lightweight building blocks, partitions, and slabs, for which there exists a wide market.

These highly beneficial properties of the material are due to its high porosity, as well as to the fact that the pores are infinitesimally small. A remarkable characteristic of the natural clay content, also, is that it possesses mechanical strength greater than would be expected from a material so porous.

Cold storage and refrigeration.

It appears almost an anomaly to say that "Fosalsil" is as valuable a material in the conservation of cold, as in conservation of heat, but this is so, and emphasises its remarkable characteristics. Especially in view of the recent Government prohibition of deleterious preservatives in foodstuffs, modern architects and others will welcome the proved efficacy of a perfect insulating material for cold storage rooms and for the increasing number of refrigerating plants he may be called upon to house. It is not intended that "Fosalsil" should replace cork, but that it should be used in conjunction with it and so bring about greater efficiency.

To illustrate the extraordinary insulating capacity of "Fosalsil" and its almost complete resistance to heat, the following extremely simple but conclusive tests, under proper expert supervision, were recently made:—

Conveying raw material into the Works at Colchester.

1. A small tin, coated with about $\frac{1}{4}$ inch of "Fosalsil" was filled with red-hot coals, but was held in the naked hand without discomfiture until the contents themselves had cooled.

2. A firebrick, a building brick, a slab of "Fosalsil" and a cube of concrete were placed in front of a fire for 15 minutes at equal distance. While the other materials were far too hot to touch, the slab of "Fosalsil" was found to be quite cool.

3. A strip of "Fosalsil," 4 or 5 inches in length, was made red-hot at one end by direct contact with a blow-pipe, but could comfortably be held in the naked fingers at the other end.

The conservation of heat.—*Furnaces, Boiler Houses, Kilns, etc.*

For furnace work it is generally known that the insulating coverings for preventing heat losses from boilers and steam pipes have usually been composed of fossil meal or " Kieselguhr," which is very similar in physical structure to " Fosalsil."

The two materials, however, differ in one extremely important respect, that while fossil meal cannot be rendered plastic without an added ingredient, " Fosalsil " is furnished by nature with a definite and sufficient proportion of natural material.

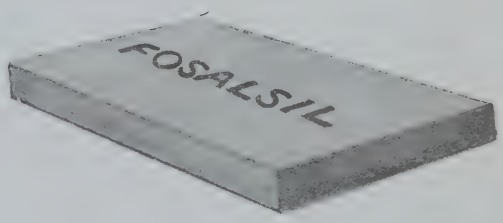
In view of the imperative necessity and ceaseless search for the reduction of overhead expenses and maintenance costs in interior heating—especially where central heating systems are automatically regulated by a thermostat to a mean temperature—the importance of " Fosalsil " partition, flooring and external walls is becoming more and more realised by architects, to whom the word efficiency is of paramount significance.

The importance of insulation.

Of late years the attention of engineers and architects has been closely occupied with the question of insulation, not only for furnace work, boiler houses, etc., in which the conservation of heat is an important economic factor, and for cold storages and refrigerator plants in which the conservation of cold is equally essential, but for practically every kind of building, whether for hotel, dwelling house, business premises or institution.

The variable climate in which we live has made it specially desirable to secure such conditions of interior temperature as will not easily be affected by exterior changes, and a great variety of materials has been experimented with in order to achieve this end, as well as considerable ingenuity being exercised in the design of hollow or specially lined walls.

" Fosalsil" Brick.



" Fosalsil" Slab.

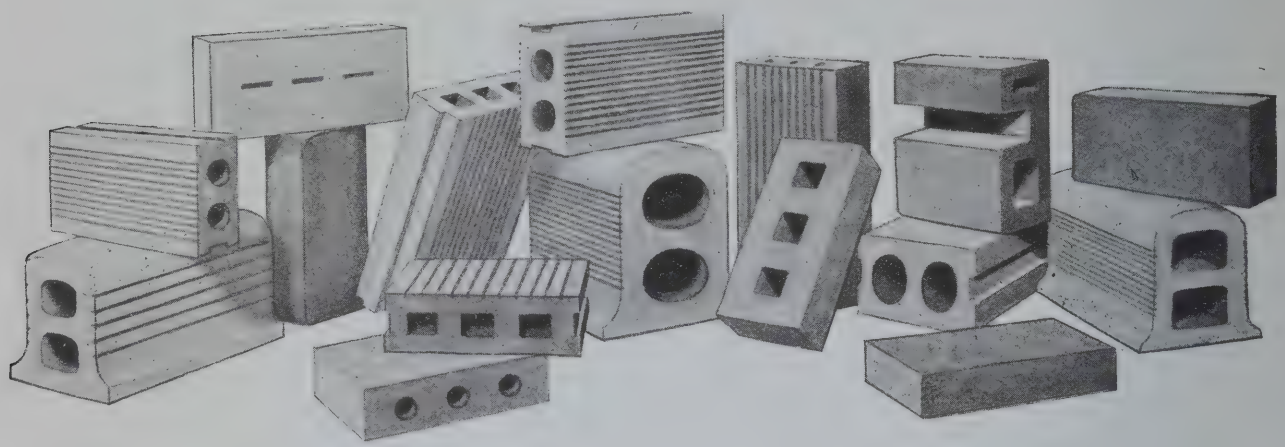
Two grades of insulating bricks are manufactured—high porous and solid—and it depends almost entirely upon the manner in which the insulator is to be used which of the grades should be employed. The high porous brick has a higher efficiency than the solid type and is recommended for use as an internal insulator or as a lining to ordinary firebricks. Solid bricks: The solid type of brick has a greater mechanical strength than the above, the average crushing strength being approximately half a ton to the square inch. Many well-known gas companies and steel works have used this type as an outside wall instead of a double wall of firebrick, thereby preventing the radiation of heat which occurs when the outside wall of a gas retort or furnace is built of firebrick or other material.

Slabs made of " Fosalsil " as linings, auxiliary linings, tilings and other uses are also in particular demand, as they can be nailed, sawn or tooled, are absolutely fireproof, and can be supplied to any dimensions, grooved or otherwise.

"Fosalsil" covering composition cement is made in two grades for insulating steam and water pipes, boilers, furnaces and tanks:—

(1) Calcinated moler and asbestos for high temperatures.

(2) Raw Moler and asbestos for lower temperatures and low-temperature steam pipes, etc.



A few of the numerous "Fosalsil" products.

Manufactured by:

MOLER PRODUCTS, LTD.

Works at Colchester.

SOLE SELLING AGENTS:

(ESTABLISHED 1857)

J. H. SANKEY & SON, LTD.,

(CANNING TOWN)

Head Office: ESSEX WHARF, CANNING TOWN, LONDON, E.16.

"FOSALSIL" SALES DEPT. - - - - - - 7/8 NORFOLK STREET, LONDON, W.C.2.

PRACTICAL APPLICATIONS OF SUBMERGED COMBUSTION.

The application of submerged combustion to the many industrial uses for which it is admirably suited, has in the past been slow, largely due to imperfections in the combustion unit. This difficulty has been overcome in the Hammond System, the distinctive feature of which is, that under all conditions of operation the maximum efficiency is obtained and the combustion unit does not suffer deterioration.

Despite the relatively recent development of the Hammond System, the results already attained have placed the process of submerged combustion on a plane of wide practical application, so that its important and characteristic features can be employed to obtain high heating efficiencies hitherto impossible.

The range of uses to which such a system of submerged combustion can be applied is too extensive to enumerate in detail. Combustion engineers will, unquestionably, appreciate the possibilities inherent in an apparatus which will impart 100 per cent. of a fuel's heat energy to a fluid, and at the same time stand up to conditions of service for an indefinite period, without suffering deterioration from over-heating and similar causes. However, a few of the applications of the Hammond Submerged Combustion System may serve to indicate the directions in which the system is finding immediate scope.

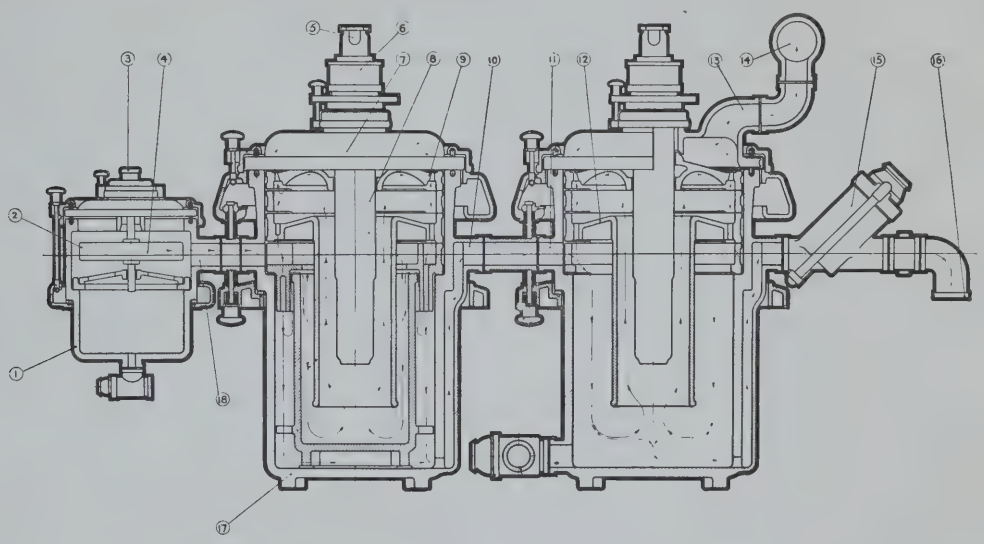


FIG. 1.—*Hammond Submerged-Combustion Chemical-Concentration Plant.*

1.—Float Chamber. 2.—Float Valve. 3.—Liquor Inlet. 4.—Liquor Level. 5.—Gas Inlet. 6.—Air Inlet. 7.—Cover. 8.—Combustion Unit. 9.—Deflector. 10.—Outlet. 11.—Inlet. 12.—Air-lift Cylinder. 13.—Steam-exhaust Outlet. 14.—Exhaust Conduit. 15.—Flow-regulating Valve. 16.—Concentrate Outlet. 17.—Concentration Vessel. 18.—Feed Outlet.

HAMMOND SUBMERGED-COMBUSTION CHEMICAL-CONCENTRATION PLANT.

In the application of heat to certain chemical liquors which must be handled in acid-resisting vessels, great difficulty is often experienced, due to the poor heat conductivity of the wall of the vessel. Many materials which are resistant to chemical action fracture or craze when subjected to severe temperature gradients. Such a difficulty is entirely obviated when heating by the submerged flame, since no flame comes into contact with the walls of the containing vessel. It has been found entirely practical to use all-stoneware apparatus in the concentration of ammonium chloride required to be of exceptional purity and free from iron or other contamination. This plant is shown in Fig. 1, in which a group of two standard units in an all-stoneware chemical-concentration battery is illustrated. These may be arranged in series in any desired number. Their operation is, briefly, as follows:—

Weak liquor enters the system by way of a float chamber through the feed connection 3. The chamber is so situated as to maintain a constant level in the main vessels 17. The combustion units 8 are centrally mounted on the covers 7, and the flame zone is constricted by the air-lift foot pieces 12, which surround the nozzles of the combustion units. The column of liquor in this space is displaced upwards,

due to aeration by the flame, and displaced by the heavier liquor in the vessel outside. The deflectors 9 cast the liquor down and the steam and combustion gases separate out and find egress by the outlets 13 to the exhaust trunk 14, from whence their heat is utilised to preheat the incoming liquor. The liquor thus circulated becomes more and more highly concentrated with each circuit and, by a system of classification, the more highly concentrated liquor in each vessel tends to collect in the lower part of each system, whence it is led to the next vessel in the series.

The rate at which the run-off is conducted determines the degree of concentration which is reached; any run-off being immediately made up by the float feed to the weak incoming liquor.

Replacements of the various parts are easily effected and any vessel may be removed without disturbing the air, fuel or steam connections. The apparatus lends itself to a great number of variations of arrangement.

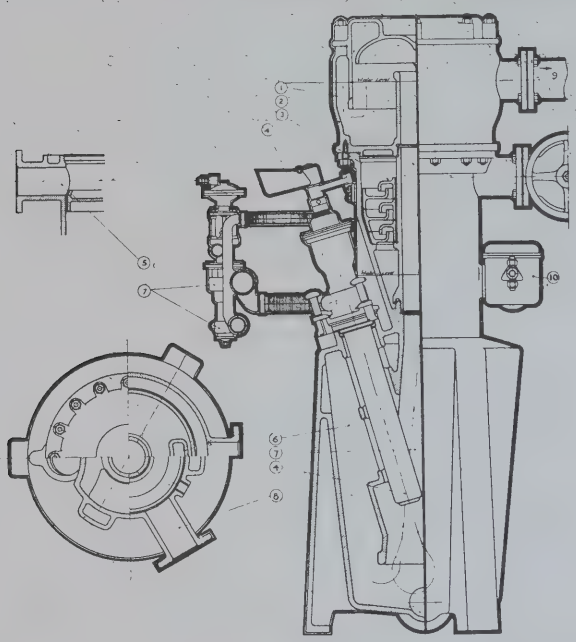


FIG. 2.—*Hammond L.P. Hot-water Central Heating System.*
1.—Seal. 2. Head. 3.—Heat Interchanger. 4.—Combustion Element. 5.—Cold Exhaust Outlet. 6.—Water Container. 7.—Air-lift Foot Piece. 8.—Return Water Inlet. 9.—Head Tank. 10.—Ball-feed Chamber.

In addition to the concentration of ammonium chloride, the system is readily adapted to the evaporation of solutions of calcium chloride, ferric chloride, magnesium chloride, zinc chloride, ammonium nitrate, weak solutions of nitric acid, sulphuric acid, ammonium thiocyanate, sodium thiosulphate, sulphate of alumina, etc. Other applications are the concentration of phosphoric-acid solutions, the carbonating of beet-sugar solutions at the lime stage, prior to passing the liquor to the filters, and the heating and agitation of certain vat dyes, in which application it avoids the troublesome dilution that has arisen when direct steam has been employed as a heating and agitating medium.

HAMMOND L.P. HOT-WATER CENTRAL-HEATING SYSTEM.

The application of the Hammond System to central heating by low-pressure hot water is shown in the accompanying diagrammatic drawing (Fig. 2).

The combustion element 4 both heats and aerates the ascending column of water in the air-lift foot piece 7, situated in the water container 6. The heated water is lifted through 7 into the head 2, where it is deflected downwards by the baffle where the gases and water vapour separate out; the water having egress through the seal 1 into the head tank 9, and the gases and water vapour escaping through ducts to the space above the water level in 6, where they escape through the heat interchanger 3, by the outlet 5.

In this heat interchanger the gases and vapour meet the incoming return water through 8, plus make-up water from the ball-feed 10 falling through the tray sections. The steam or water vapour condenses in the cold return, and the gases leave the apparatus at the lowest temperature of the system. The ball-feed in chamber 10 is operated by the level in 6, but delivers the make-up water through the heat interchanger.

The heating unit is situated at the top floor of the building, being heated and operated by "downward displacement," since circulation is by an increased head on the hot side, which displaces the water up the cold leg of the system on its return by way of the heat interchanger 3 to the base chamber 6, where the heating unit raises it once more by air-lift to the head tank. The supply of the fuel and air to the combustion unit is thermostatically controlled.

For full particulars and details of the Hammond Submerged Combustion System apply to:—

SUBMERGED COMBUSTION, LIMITED,
28, Victoria Street, Westminster, S.W.1.

CLASSIFIED LIST

OF

PLANT AND APPLIANCES.

ACCUMULATORS, STEAM.

Aerogen Co., Ltd.
Postal Address: 36, Bolsover Street, London, W.1.
Telegraphic Address: Aerogen, Eusroad, London; Telephone No.: Museum 7078.

Fairfield-Howden Ruths Steam Accumulators, Ltd.
Postal Address: 195, Scotland Street, Glasgow, C.5.
Telegraphic Address: Ruthsaccum, Glasgow; Telephone No.: South 2070.

AIR HEATERS.

Howden-Ljungstrom Preheaters (Land), Ltd.
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Telegraphic Address: Preheating, Parl; Telephone No.: Victoria 5606, 2855.

Underfeed Stoker Co., Ltd.
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Telegraphic Address: Underfeed, London; Telephone No.: Holborn 2002.

AIR METERS.

George Kent, Ltd.
Postal Address: Biscot Road Works, Luton, Beds.
Telegraphic Address: Kents, Luton; Telephone No.: Luton 790. (London Office: 199, High Holborn, W.C.1. Telegrams: Kentobin, Westcent, London; Telephone No. : Museum 4262.)

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Underfeed Stoker Co., Ltd.
Postal Address: Africa House, Kingsway, London, W.C.2.
Telegraphic Address: Underfeed, London; Telephone No.: Holborn 2002.

AUTOMATIC COAL WEIGHERS.

W. & T. Avery, Ltd.
Postal Address: Soho Foundry, Birmingham.
Telegraphic Address: Avery, Birmingham; Telephone No.: Smethwick 300.

BOILER CONTROL APPARATUS.

Industrial Combustion Engineers, Ltd.
Postal Address: 31, Wybert Street, London, N.W.1.
Telegraphic Address: Duscom, Eusroad, London; Telephone No.: Museum 7604.

BOILER EQUIPMENT.

A. B. Cleworth & Co., Ltd.
Postal Address: 118, Queen Victoria Street, London, E.C.4.
Telegraphic Address: Clewcoba, London; Telephone No.: Central 8136-7.

Aerogen Co., Ltd.
Postal Address: 36, Bolsover Street, London, W.1.
Telegraphic Address: Aerogen, Eusroad, London; Telephone No.: Museum 7078.

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Postal Address: 195, Scotland Street, Glasgow, C.5.
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